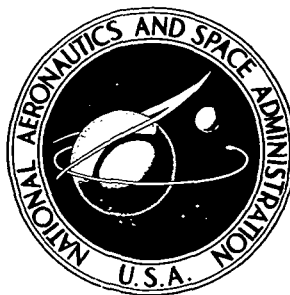


**NASA CONTRACTOR  
REPORT**



**NASA CR-2511**

**NASA CR-2511**

**AN ELECTRONIC SYSTEM FOR MEASURING  
THERMOPHYSICAL PROPERTIES  
OF WIND TUNNEL MODELS**

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*Prepared by*

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16. Abstract <p>This electronic system is a part of another apparatus which supplies a step input of constant heating rate to a one foot square area in which both a reference heat gauge and a model or sample is placed. The primary apparatus and its operational characteristics are described in NASA CR-2434. The electronic system described herein measures the surface temperature of a small portion of the surface of the model or sample at high speeds using an infrared radiometer and processes this data along with heating rate data from the reference heat gauge in a small computer and prints out the desired thermophysical properties, time, surface temperature, and reference heat rate. This system allows fast and accurate property measurements over thirty temperature increments in only a few minutes.</p> <p>This report describes the technique, the details of the apparatus, the procedure for making these measurements, and the results of some preliminary tests.</p>					
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## FOREWORD

This final report was prepared by Beta Industries, Inc. under Contract NAS1-12127, Design, Develop, Fabricate and Install an Electronic System for Measuring Thermophysical Properties of Wind Tunnel Models. It covers the period of 22 February 1973 through 15 April 1974. This work was performed for the National Aeronautics and Space Administration, Langley Research Center, under the direction of the Hypersonic Vehicles Division.

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## SECTION 1

### INTRODUCTION

An electronic system for measuring the thermophysical parameters of small complex wind tunnel models has been developed. The system measures surface temperature remotely at high speeds using an infrared radiometer and processes this data along with heating rate data using a small computer.

The theory of the measurement is based upon previously developed techniques (References 1 and 2) using phase-change coatings. This technique consists of using a model made from a low thermal conductivity material covered with a phase-change coating which is an accurate surface temperature indicator. This indicator called "Tempilaq" consists of wax crystals which melt at a prescribed melting temperature. If the model is heated, the coating will melt when the surface reaches the calibrated phase-change temperature. Knowing this melt temperature, the time to reach the melt temperature from the initial temperature, and the heating rate, the combination of thermophysical properties  $\sqrt{\rho ck}$  can be determined from the formula (Reference 1):

$$\sqrt{\rho ck} = \frac{\dot{Q}}{T - T_i} \frac{2}{\sqrt{\pi}} \sqrt{t} \quad (1)$$

where

$\dot{Q}$  = the imposed heating rate,

$T_i$  = the initial model temperature prior to heating,

$T$  = the melting temperature,

$t$  = elapsed time from the onset of heating until melting occurs,

$\rho$  = the density,

$c$  = the specific heat, and

$k$  = the thermal conductivity.

Measuring an effective  $\sqrt{\rho c k}$  by this procedure provides an accurate determination of the aerodynamic heat transfer to the models when tested in the wind tunnel.

The electronic system described in the report is based upon the above technique except that the temperature,  $T$ , is continuously monitored by an infrared thermometer and the corresponding elapsed time is accurately recorded by an electronic data handling system. Some of the advantages of this system are that it performs the measurements over thirty temperature increments in only a few minutes. There is no uncertainty in the elapsed time measurement due to the slow melting of the phase-change coating. This system can be used with models which are either uncoated or coated. Results from both measurement techniques can be compared.

This report describes the technique for measuring  $\sqrt{\rho c k}$ , the details of the apparatus, the procedure for making these measurements, and the results of some preliminary tests.



## SECTION 2

### DESCRIPTION OF MEASUREMENT SYSTEM

Figure 1 shows a block diagram of the thermophysical properties measurement system. The specimen holder, heat source, and water cooled shutters were developed under a separate effort and are described in Reference 2. Figure 2 is a photograph of this apparatus with the heat source detached. This apparatus supports the infrared thermometer, radiometer head, and the phase-change detector. A microswitch is attached underneath the water cooled shutter which is tripped just as the shutter passes over the region of the specimen which is being measured by the infrared thermometer. This signal represents the start of the elapsed time or the input heating rate step function (Reference 1).

Referring to Figure 1, a specimen is placed in its holders in front of the heat source. With the heat source off, the infrared radiometer is sighted onto the region of the specimen to be measured. If the specimen is in thermal equilibrium with the ambient, its temperature is measured using a surface contacting thermometer. This temperature is entered into the computer through the teletype and the emissivity control is adjusted until the infrared radiometer reads the same temperature. The heat lamps are then turned on and the shutter is opened. This closes the microswitch which starts the A-D converter, and both heat gauge and specimen temperature are stored in the computer. When all of the data is stored,  $\sqrt{\rho c k}$  is computed as a function of the specimen temperature.

An optical radiometer has been developed which detects the reflected light from the heat source. This can be used to detect the phase change of coated

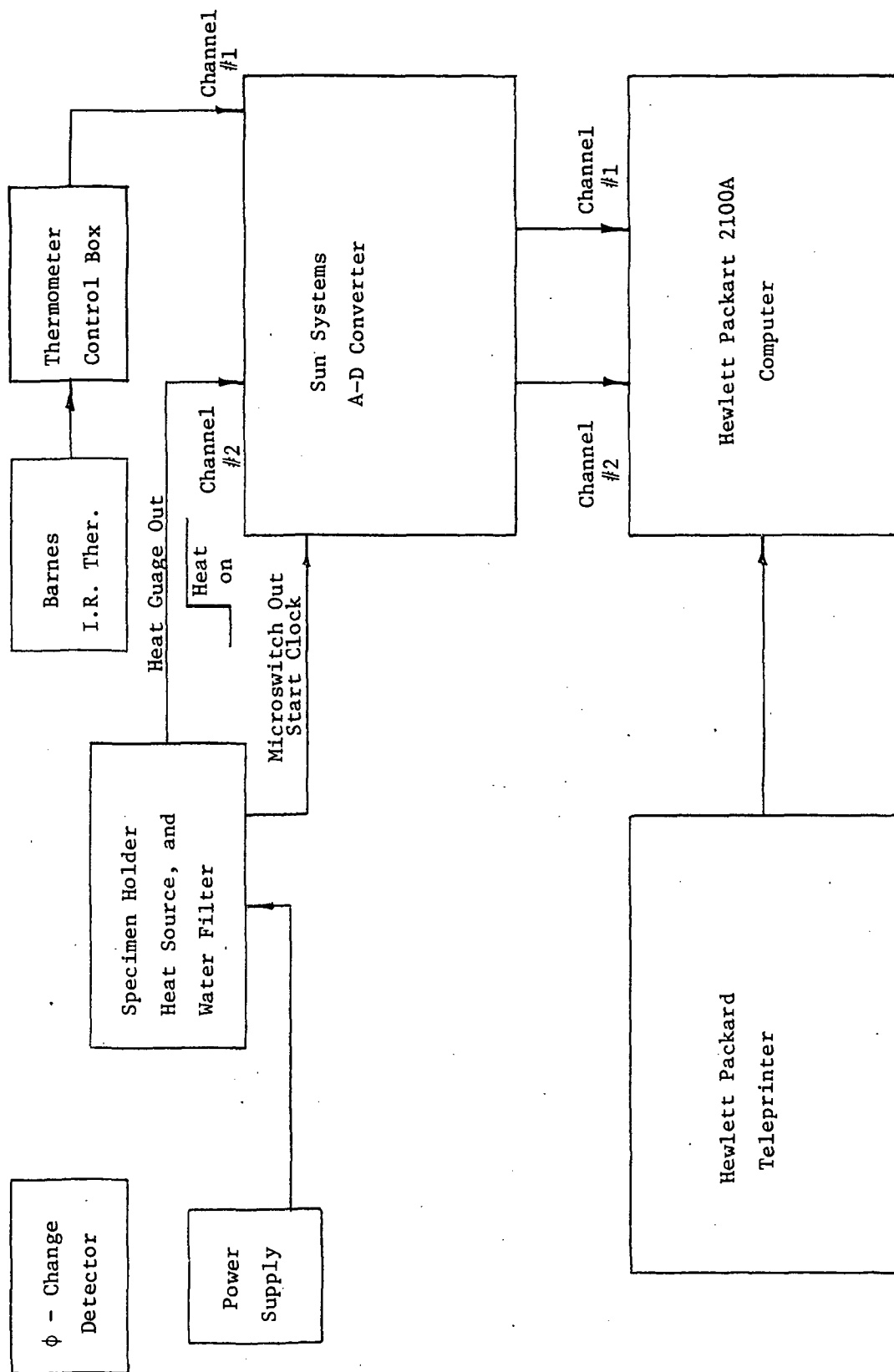


Figure 1. Block Diagram of Thermophysical Properties Measurement System

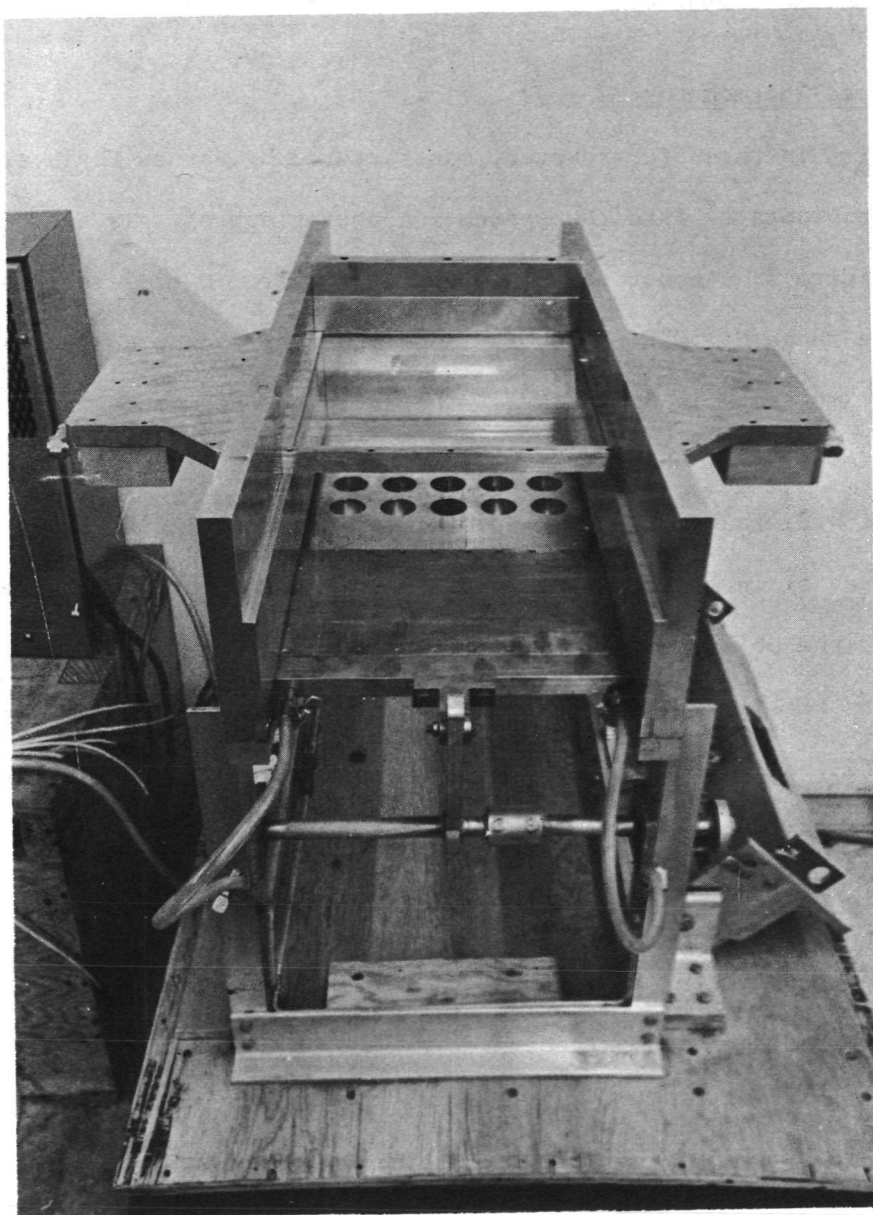


Figure 2. Photograph of Thermophysical Properties Measurement Apparatus with Heat Source Not Shown

specimens, since there is a corresponding change in the reflectance at visible wavelengths.

The remainder of this section describes in more detail the various components of the measurement system.

## 2.1 Infrared Thermometer

A Model IT-7E infrared thermometer, manufactured by Barnes Engineering Company, has been incorporated into the system. A photograph of this instrument is shown in Figure 3. An output voltage swing of from 0 to 5 volts spans the temperature range of 50°F to 500°F. A printout of the output voltage versus temperature is shown in Appendix A. The infrared thermometer lens has a field of view of 0.7° which will measure the temperature over a 0.4 inch target spot at a distance of 20 inches. Aiming and focusing of the radiometer onto the area of interest is accomplished by in-line, through-the-lens viewing. By focusing the objective lens a reticle in the eye piece indicates to the observer the precise region of the specimen where temperature is to be measured. Additional specifications and operating instructions are given in the original manufacturer's operations manual which has been provided with the system.

The infrared thermometer is supported by a mount which allows it to be maneuvered in several degrees of freedom.

### 2.1.1 Temperature Calibration

The calibrated output of the radiometer is based on the assumption that the specimen is a perfect blackbody radiator with an emissivity of one. The radiative characteristics of "Stycast," a high temperature plastic, which contains



Figure 3. Photograph of Barnes Model IT-7E Infrared Thermometer

a filler and other opaque plastics. We have verified that the transmittance of this material over the passband of the radiometer is very small for sample thicknesses, less than 0.010 inches. This means that the surface temperature of the specimens will be measured by the radiometer. Since these plastics are dielectrics the emissivity of samples with rough surfaces will be one minus the surface reflectance, or their emissivities will be very close to unity (Reference 2). This means that the ratio of the true temperature of the sample to the blackbody temperature is a constant and can be accounted for by adjusting the emissivity of the infrared thermometer.

A surface contacting thermometer (GFE) is used to measure the specimen temperature once it has stabilized at the ambient temperature and just prior to initiating the test. This reading is entered into the computer as the initial model temperature.

#### 2.1.2 Water Absorption Filter

Since the radiant heat source will be at a temperature of 5000°F, it will emit a considerable amount of radiation over the passband of the infrared radiometer. The envelopes of the heating lamps are made of high temperature quartz which consist almost entirely of silica. These materials absorb much of the radiation at wavelengths larger than 5 microns.

The absorbed radiation will raise the quartz envelope temperature considerably higher than the lowest temperature to be measured by the radiometer. The envelopes will then reradiate at relatively long wavelengths extending over the passband of the radiometer. Although the reflectance of the target

specimens are small (less than 5%) at these wavelengths and both the quartz envelopes and the target specimens are diffuse radiators and reflectors, this reradiated energy nevertheless can represent a significant noise source to the radiometer.

To eliminate this noise source a water absorption filter has been developed and mounted between the specimen and the heating lamps (see Figure 2). A thin layer of water is passed between two parallel glass plates. The cooling water will absorb all wavelengths larger than about 1.8 microns (Reference 4) including the radiation within the spectral passband of the radiometer.

Engineering drawings of the water filter have been provided with the system.

An automatic water flow interlock manufactured by Hays Manufacturing Co. has been provided to insure that water is flowing before electrical power to the radiant heat source is initiated.

## 2.2 Phase-Change Detector

This is essentially an optical radiometer which senses the heat source radiation which is reflected from the specimen. Photographs are shown in Figures 4 and 5. Specifications for this detector are listed below.

1. Diameter of specimen imaged onto the photodetector at a distance of 11 inches: less than 0.4 inches.
2. Aperture opening diameter can be varied from 3/32 inches up to one inch.
3. Photodetector: Motorola MRD 300.



Figure 4. Photograph of Phase-Change Detector

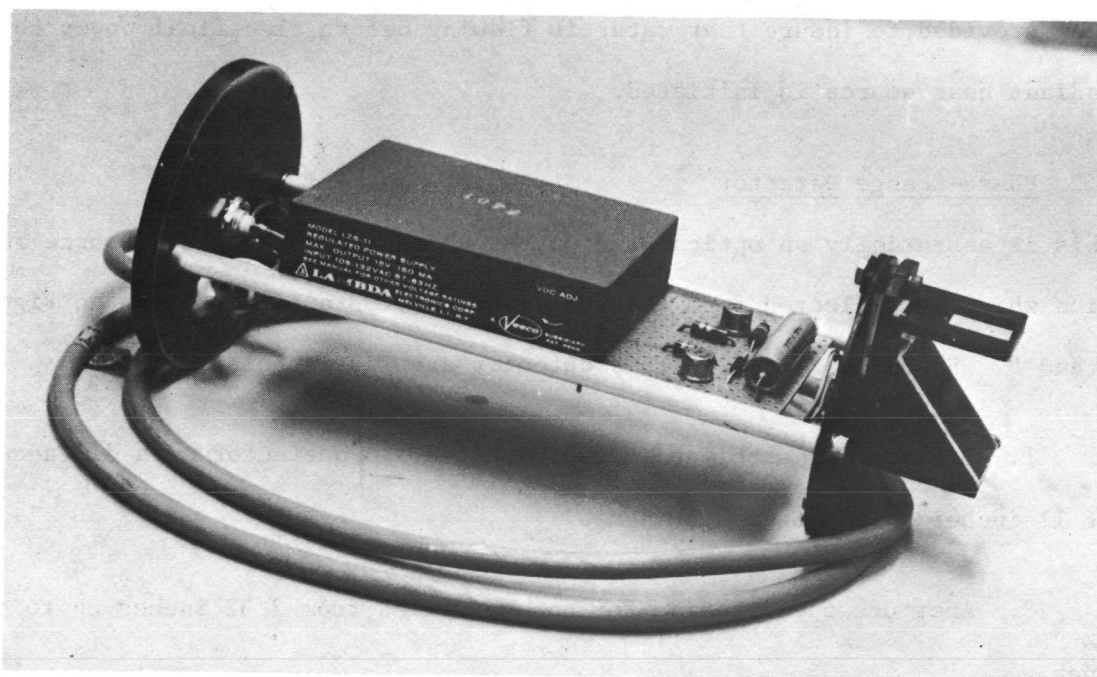


Figure 5. Photograph of Internal Electronics of Phase-Change Detector



4. Sighting is provided by a beam splitter, reticle, and an adjustable eyepiece lens.

5. Wavelength of maximum sensitivity: 0.8 microns.

6. Maximum output voltage: 10 volts.

7. Minimum load resistance: 50 ohms.

8. Output impedance: less than 30 ohms.

9. Response time: 5 microseconds.

10. Input power: 115 volts a.c.

The unit can be taken apart from the back for easy repair and maintenance.

An electrical schematic is shown in Appendix B.

The phase-change detector is supported by a mount which allows it to be maneuvered in several degrees of freedom.

### 2.3 Two Channel Data Handling System

This component is manufactured by Sun Systems, Inc. and is designated as the Adacus II-S. The purpose of this system is to convert the analog data from the heat gauge and the infrared thermometer into digital form so that it can be transmitted to the computer memory core. The general features include the ability to:

1. Accommodate low level transducer signals of 10 millivolts full scale output,

2. Provide a tracking A to D conversion of each input signal at rates up to 50 KHz,
3. Output data only when a preselected incremental change has occurred in the amplitude of the input signal; or output data only when a preselected time increment has occurred; or simultaneously acquire data from both channels whenever a preselected incremental change has occurred in the amplitude of one input signal,
4. Provide the necessary commands to control the computer memory core,
5. Provide for a connection which will allow one channel to be slaved to the other, and
6. Provide for an optional remote control command so that data printout can be inhibited until a switch closure has occurred.

Each channel consists of a low level differential input amplifier, a tracking A to D converter, a logic detection network, buffered amplifier outputs, and an output control and storage circuit. The master clock and display functions are shared between the two channels housed in the Adacus II-S.

The original manufacturers operating manual and a complete set of electrical drawings have been provided with the system.

Figure 6 shows a photograph of the Adacus II data handling system (far left) along side of the computer system.

#### 2.4 Computer System

The computer system consists of the following Hewlett Packard items: one

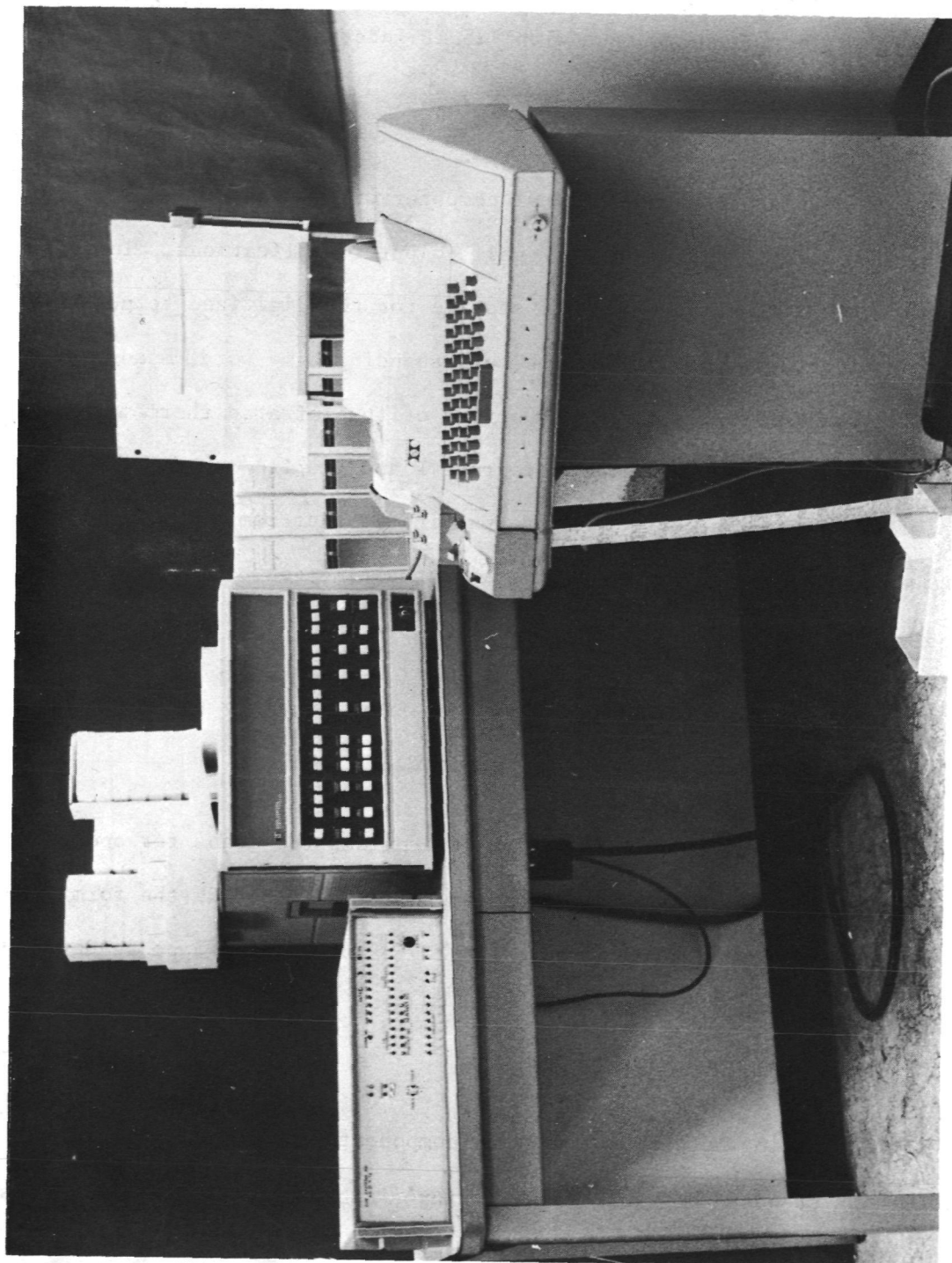


Figure 6. Photograph of Data Handling and Computer Systems

Model 2100A computer, two Model 12566A Duplex Registers, and one Model 2752 Buffered Teleprinter Input/Output with 12531B Interface Kit.

A photograph of the computer and the teletype are shown in Figure 6.

The 2100A is a general purpose digital computer with 4096 words of core memory designed for a wide range of small computer applications. In this application it provides intermediate storage for the digitized temperature and heating rate data, as well as the corresponding time word; means for linearizing the inherently nonlinear output of the infrared thermometer; scaling of both signals in terms of degrees F and Btu/ft<sup>2</sup>/sec for the computation of  $\sqrt{\rho c k}$ ; and the control and formatting so that temperature versus time, heating rate versus time, and  $\sqrt{\rho c k}$  versus time can be listed on the teletype.

The 12566A Duplex Registers provides the required circuitry for interfacing the Two Channel Data System with the computer.

The 2752 Buffered Teleprinter Input/Output provides the means for operator communication with the computer. This communication can take the form of commands or instructions entered through the keyboard or paper tape reader by the operator, or printed output from the computer to the operator.

## 2.5 Interface Wiring

All interface wiring between the various components shown in Figure 1 are provided with standard original manufacturer's cables except the two inputs to and outputs from the Adacus II. Diagrams of these four cables are shown in Appendix C. The channel 1 cable connecting the output of the Adacus II

with the Hewlett Packard computer (Figure C-2) is set up to accept the cable from the microswitch mounted underneath the water cooled shutter. Also, this cable is wired so that Channel 2 of the Adacus II is slaved to Channel 1. This insures that the time word is the same for both channels.

## SECTION 3

### SOFTWARE

The purpose of this section is to clarify some definitions and procedures which are unique to the operation of the Hewlett Packard, Model 2100 A computer, with 4K memory. This section is not to replace any of the Hewlett Packard manuals, but should be used to tie various procedures together in the proper order and to explain some of the terms which are used in these procedures.

#### 3.1 Tapes

The Hewlett Packard computer is received from the factory with 32 tapes. Some of these tapes are used to generate control systems, input/output drivers, debug routines, compilers and editors. The rest of the tapes are used for system check out and repair should a malfunction occur. Beta Industries, Inc. has already generated some of the control system routines, compilers, and input/output routines which were required in order to generate our program. These tapes will be supplied in addition to the 32 supplied by Hewlett Packard.

Table 1 contains a list of the Hewlett Packard supplied tapes for malfunction trouble shooting and system check out. The tapes included in this list should be set aside from those which are to be used for everyday computer operation.

TABLE 1

<u>Number</u>	<u>Name</u>	<u>Quantity</u>
24163-60001 REV A	General Purpose Register Diagnostic Binary	2
24193-60001 REV A	2100 Cold Memory Pattern Test Binary	1
24194-60001 REV A	2100 High Memory Pattern Test Binary	1
24196-60001 REV A	General Purpose Register Test Binary	2

TABLE 1 (Cont'd)

24198-60001 REV B	2100 Memory Parity Check Test Binary	1
24201-60001 REV A	2100 TTY Test Binary	1
24206-60001 REV B	2100 Power Fail Diagnostic Binary	1
24208-60001 REV A	2100 Alter-Skip Instruction Test Binary	1
24209-60001 REV A	2100 Memory Ref. Instruction Test Binary	1
24210-60001 REV A	2100 Shift-Rotate Instruction Test Binary	1
24211-60001 REV A	2100 Low Memory Address Test Binary	1
24212-60001 REV A	2100 High Memory Address Test Binary	1
4214-60001 REV A	2100 Extended Arithmetic Unit Test Binary	1
24215-60001 REV A	2100 Interrupt Test Binary	1
24222-60001 REV A	2100 Memory Protect Test Binary	1

Table 2 contains tapes which will be used for everyday general system use.

In particular, these tapes are used to assemble compilers, input/output drivers, and system control tapes. Generally, these tapes will only be used to replace a configured tape which has been worn or damaged.

TABLE 2

A. Basic Control System Tapes

<u>Number</u>	<u>NAME</u>	<u>Quantity</u>
20021-60001 REV C	Prepare Control System Binary	1
20017-60001 REV C	BCS TTY Driver D.00 Binary	1

TABLE 2 (Cont'd)

A. Basic Control System Tapes (Cont'd)

<u>Number</u>	<u>NAME</u>	<u>Quantity</u>
24173-60001 REV A	Input/Output Control Binary	1
20001-60001 REV D	4K BCS Relocating Loader Binary	1

B. Input/Output Drivers

<u>Number</u>	<u>NAME</u>	<u>Quantity</u>
24123-60001 REV A	4K SIO TTY Driver Binary	1
20301-60001 REV C	4K SIO System Dump	1

C. Compilers--Symbolic Editors--Cross Reference Generators

<u>Number</u>	<u>NAME</u>	<u>Quantity</u>
24039-60001 REV B	4K Assembler EAU Binary	1
20549-60001 REV A	4K Fortran Compiler Pass 1 Binary	1
20549-60002 REV A	4K Fortran Compiler Pass 2 Binary	1
20549-60003 REV A	4K Fortran Compiler Pass 3 Binary	1
20549-60004 REV A	4K Fortran Compiler Pass 4 Binary	1
20100-60001 REV B	Symbolic Editor Binary	1
24109-60001 REV B	Cross Reference Symbol Table Generator Binary	1

D. Subroutine Library--Debug Routine

<u>Number</u>	<u>NAME</u>	<u>Quantity</u>
24148-60001 REV B	4K BCS Relocatable Library Binary	1
20002-60001 REV B	BCS Debug Routine	1



### 3.2 Configured Tapes

The Hewlett Packard 2100A computer is the most basic system available and therefore its operation is basic. The operation of the Hewlett Packard computer is unlike larger computers where a tape or card deck is loaded and compilation and execution takes place in one automatic operation, rather its operation consists of loading a series of tapes to fabricate a program tape. The program tape is then reloaded and executed. A schematic diagram shows the procedure in Figure 7.

A program tape is supplied by Beta Industries, Inc. which will perform the data acquisition and computation functions. Should this program tape become damaged, worn or outdated a new program tape will have to be configured. Procedures for configuring the computer tapes will be outlined in the following sections.

Note if only one tape is damaged it is not necessary to refabricate all tapes, rather only the tapes pertinent to the damaged unit. However, if new equipment is added to the system, such as a high speed reader, a new series of tapes must be generated excluding those supplied by Hewlett Packard.

#### 3.2.1 BCS Tapes

The first tape that must be generated is the configured BCS tape. This tape is fabricated according to Hewlett Packard Binder No. 5, Publication No. 5951-1391, "Basic Control System," Procedure No. 1, using tapes listed in Table 2A. In this procedure the computer asks for information on the teletype printer and halts, waiting for the programmer to enter the information. Beta Industries has compiled a list of information entered on its configured BCS tape, BII 1. The information is listed below by step number in the required procedure. Numbers in brackets cannot be changed unless the available equipment (i.e., computer and associated hardware) are changed.

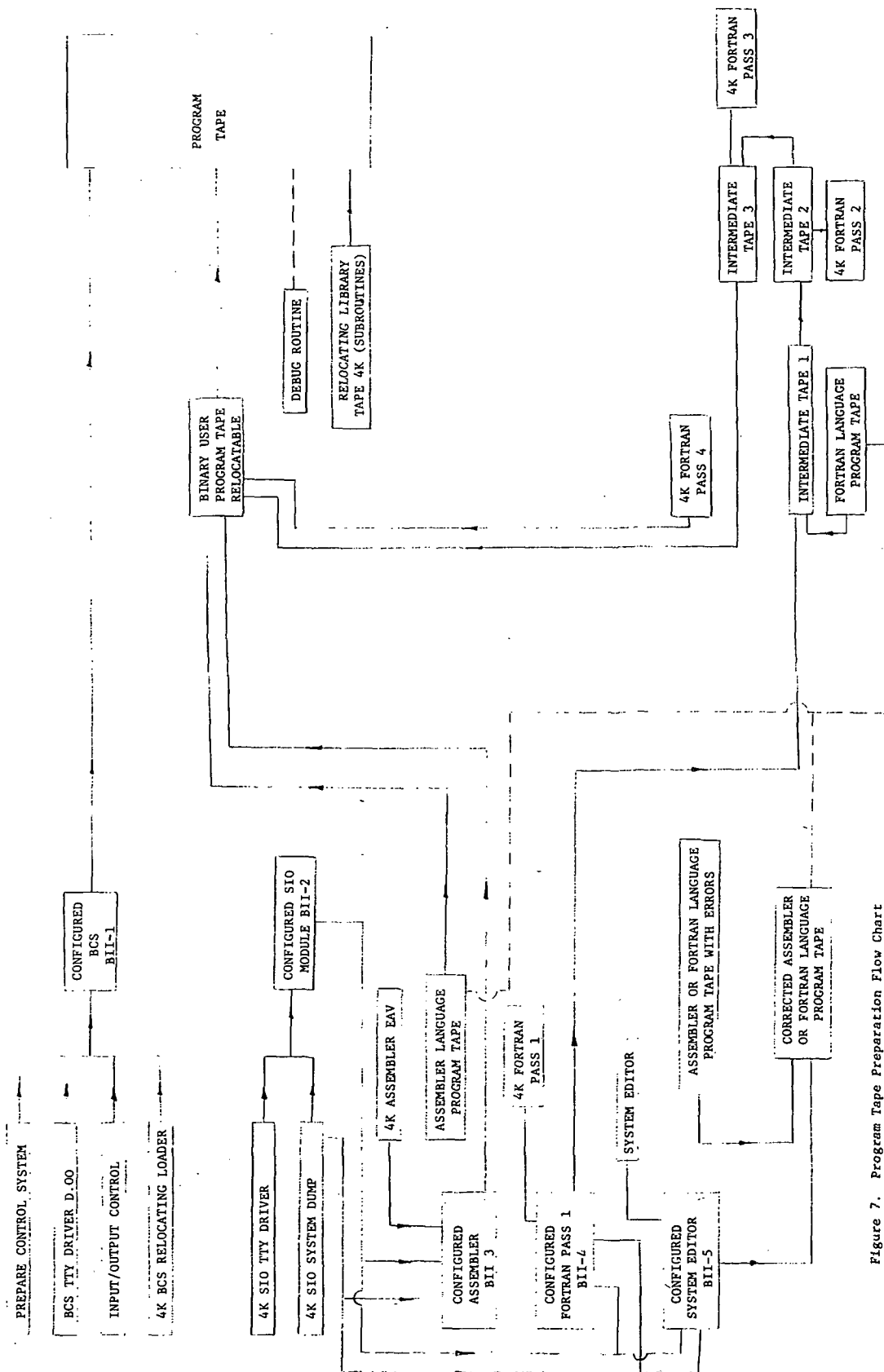


Figure 7. Program Tape Preparation Flow Chart

STEP No. 7	[ $\phi\phi$ ]--fixed by input/output device
STEP No. 8	[ $\phi\phi$ ]--fixed by input/output device
STEP No. 9	[7677]--fixed for 4K memory
STEP No. 10	15--user's discretion
STEP No. 12	[10,D.00]--fixed by input/output device
STEP No. 13	[7] all questions
STEP No. 14	[ $\phi$ ]--no access
STEP No. 16	[10,14,I.00]*Note: No. 14 in brackets can be changed to one less than number entered in Step 10.

13,0 This reply sets an assembler NOP  
statement at these memory loca-  
12,0 tions in order to permit flow of  
ADCUS data without programmed  
11,0 halts.

This tape has been configured by Beta Industries, Inc. and will be supplied as BII-1, "Configured BCS."

### 3.2.2 Input/Output Driver Tapes

The next tape which must be configured is the configured System Input/Output Module (SIO Module). This tape is configured using the tapes listed in Table 2B. These tapes are loaded according to Hewlett Packard Binder No. 5, Publication No. 5951-1374, Procedure 1. This tape will be referred to as BII-2, "Configured SIO Module."

### 3.2.3 Configured Compiler Tapes

In order to process language program tape a configured compiler tape must be fabricated. This tape is configured according to Hewlett Packard Binder No. 5, Publication No. 5951-1374, Procedure 2, using the tapes listed in Table 2C and the Configured SIO Module BII-2. A special note must be made in the case

of the Fortran compiler. The configured compiler is only needed for Pass 1 operation. Beta Industries, Inc. has configured some of these tapes and they are listed below.

BII-3, Configured Assembler

BII-4, Configured Fortran Pass 1

BII-5, Configured Symbolic Editor

The Beta Industries, Inc. source program is written in assembler language and Fortran language, therefore, to replace this program both the Configured Assembler and Configured Fortran Pass 1 will be needed. Only short Fortran programs can be loaded since the capability of the 4K memory is limited. The Beta Industries, Inc. assembler and Fortran programs of about 1100 octal words are about the maximum that can be loaded. This program leaves about 200 octal words as spares after the subroutine library has been loaded.

In the manuals, HP Basic and HP Algol language manuals are included, but the binary tapes are not included as each of these languages require 8K memory. Therefore, the option of programming in these languages is not available.

#### 3.2.4 Binary Program Tapes

The programmer has at his command two standard computer languages for use on the Hewlett Packard 2100A computer. These are HP Fortran and HP Assembler. These two languages are described in Hewlett Packard Binder No. 6. The program which is written in either one of the available languages must be compiled into machine language. This operation utilized either the Configured Assembler, BII-3, or the Configured Fortran, Pass 1, BII-4, along with Fortran Pass 2 through 4 binary. If the source program is in HP Assembler language it must be compiled according to Hewlett Packard Binder No. 5, Publication No. 5951-1390, Procedure

1. If HP Fortran is used Procedure 2 of the same publication must be used. Compilation errors are described in Binder No. 5, Publication 5951-1377. These procedures will produce a binary output tape described as a user relocatable tape or user program tape.

Should errors be detected in the source program they may be eliminated through use of the Symbolic Editor routines. This requires the use of a Configured Symbolic Editor, BII-5, and a procedure described in Hewlett Packard Binder No. 7, Publication No. 02116-9016. This will produce a corrected source language tape.

### 3.2.5 Program Tapes

Program tapes are prepared by using the Configured BCS tape, BII-1, the user relocatable program tape, the Relocating Library tape and possibly the Debug System tape. These tapes are loaded according to Hewlett Packard Binder No. 5, Publication No. 5951-1391, Procedure 3. These tapes will produce the final program tape, compiled with all input/output drivers, subroutines and system controls on it.

### 3.2.6 Other Notes

Input/output routines for HP Assembler and HP Fortran are not found in the language manual; rather, they are found in Hewlett Packard Binder No. 7, Publication No. 02116-91780; Relocatable Subroutines, Section III, The Formatter.

## 3.3 Programs BETA and ADCUS

### 3.3.1 Introduction

Program BETA, along with subroutine program ADCUS, load the binary data from A to D converter and perform the necessary calculations to arrive at the solution for time, heating rate, and the thermophysical parameter,  $\sqrt{\rho c k}$ .

Program BETA is a main line program which is written in Fortran source language. This language was chosen because of its relative simplicity and straightforwardness. Program ADCUS is a subroutine program which is written in Assembler source language. The methodology for loading the binary data from the Adacus A to D converter necessitates the use of this program. Assembler language is required because the data from the A to D converter is unformatted and uses an electronic flag signal to load from the interface buffers. Fortran source language has no provisions for clearing and setting of the flag flip-flop circuits which control the loading of the data.

Program BETA-ADCUS will automatically accept three or thirty seconds of data and calculate the time, temperature, heat flux, and root pck that occurred during the test. The printout consists of a tabulation of computed values for each 0.10 seconds or 1.0 seconds depending upon the increment selected on the A to D converter and the time constant entered on the teletype.

### 3.4 Detailed Verbal Explanation

The program is outlined in Figure 8. The following paragraphs provide a guide in following the overall flow of the routine.

#### 3.4.1 Program Initiation

The initial steps are necessary to provide enough information to the computer to process the input data and to identify the output later. This is accomplished by reading the supplied tape into the computer and "loading" in the appropriate subroutines and formats. For example, the subroutine "square root" has been taken from a library tape and included into the finished tape. Similarly, format routines are included that not only enable the computer to recognize data in a register, but also establish internal routines to output the data in an "English" format.

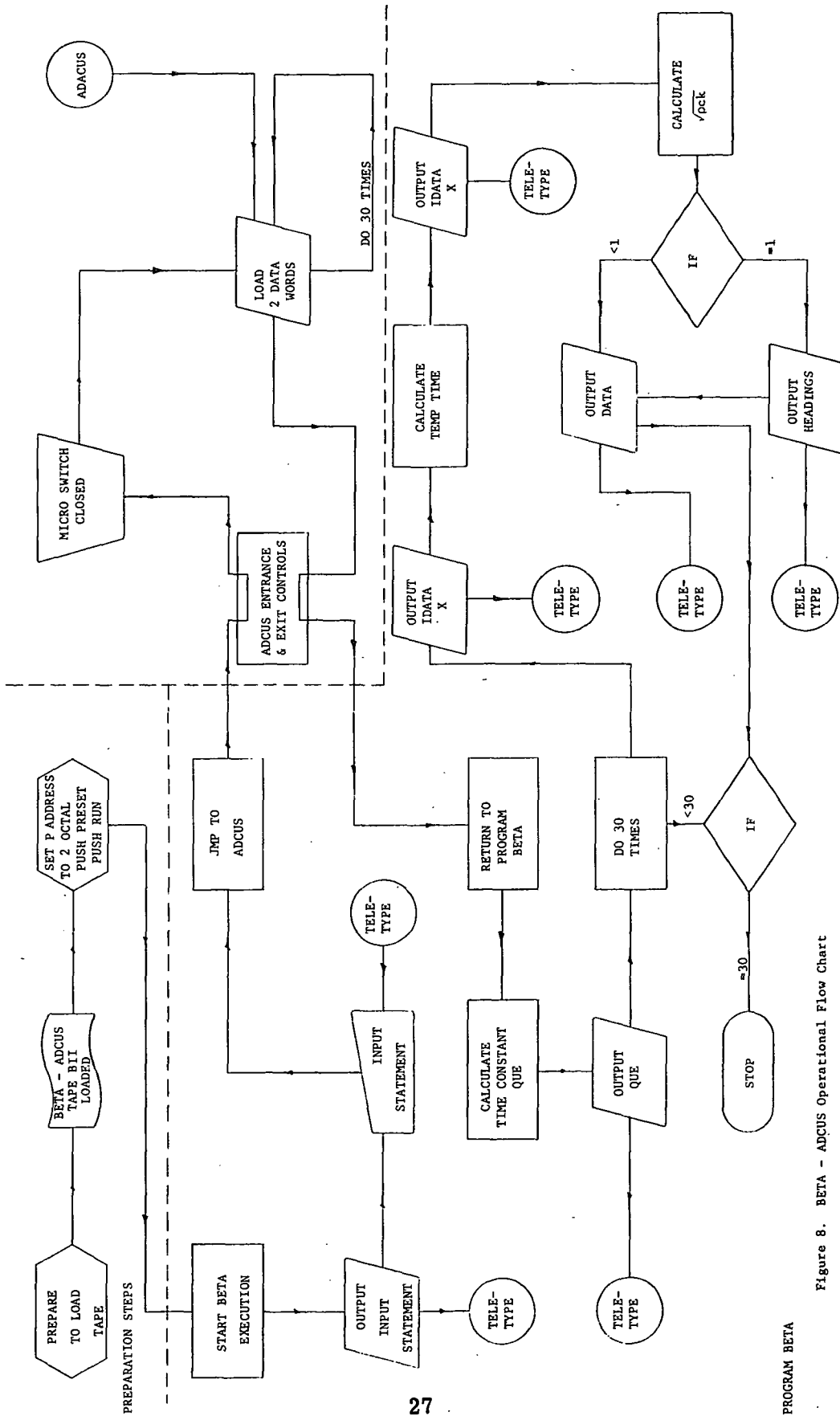


Figure 8. BETA - ADCUS Operational Flow Chart

Once the program has been loaded into the computer it requests input constants by printing out, "input the data, Format 4F9.4." At this point it is necessary to input the initial temperature, the calorimeter data, and time span desired for the experiment, either three seconds or thirty. Each calorimeter supplied has a particular value for MC/A which has been calculated. Additionally, for chromel-alumel thermocouples there is a particular value of millivolts/degree temperature change to be specified.

The computer then jumps to subroutine ADCUS where it waits until the interface card provides a signal to read in the data "words."

Another initial value is set in the computer. A counter, referred to as count, is set at a value of minus 30. As each time pair of data is read into memory, the counter is incremented by one. A test is within the program such that when count equals zero, the computer stops collecting data and returns to the main program BETA to process and print out the results.

#### 3.4.2 Read-In Measured Data

The Adacus system supplies two data words of 12 bits each. Channel 1 supplies temperature and Channel 2 supplies heat flux data. The computer reads the first word into an array, increments the address of the array and stores the second word in the next slot. The address is again incremented, the counter incremented (count) and the next two words stored. After the 30th time pair is stored, the storing is complete and the program begins processing the data.

#### 3.4.3 Calculations of the Parameters

Time is easily calculated because each reading occurs at 0.10 seconds or 1.0 seconds. Each time the program executes the "DO" loop for the calculation of



the data the proper increment is added to "TIME" and the total elapsed time is accumulated.

The temperature is calculated by using a parabolic approximation of the calibration table supplied with the Barnes sensor. In order to achieve an accuracy of less than 1.5% along the full range of the curve and yet maintain the calculations in a form which the computer can handle two equations are used. The first equation is for voltage values to the Adacus of less than 0.6 volts. The equation is:

$$T = C_1(R + C_2)^{1/2} + C_3$$

where R = Adacus register counts

$$C_1, C_2, C_3 = \text{constants}$$

The second equation is for input voltage values of greater than 0.6 volts. The equation is:

$$T = C_4(R - C_5)^{1/2} + C_6$$

where R = Adacus register counts

$$C_4, C_5, C_6 = \text{constants}$$

These two mathematical approximations provide a maximum error of 1.1% at approximately 75°F.

The heat flux is calculated by using calibration values of chromel-alumel thermocouple electromotive force versus temperature. The output is linear over the range of 25°C to 300°C within a 2% maximum and less than 1% from 100°C to 300°C. Since the flux depends upon a change in temperature,

$$\dot{Q} = \frac{MC}{A} \frac{dT}{dt}$$

Thirty values of the heat gauge output are read and stored. If the heat source has been allowed to reach thermal equilibrium before the shutter is opened,

then the flux should be very nearly constant during the run. Since the heat guage output voltage is linear with respect to its temperature and the time increments between measurements are constant, a good average measurement of the heat flux can be obtained from the 30th and 5th readings. These values are used to calculate the heat rate from the equation:

$$\dot{Q} = \frac{MC}{A} \left( \frac{T_{30} - T_5}{t_{30} - t_5} \right)$$

where

T = calorimeter temperature

t = time

$\frac{MC}{A}$  = calorimeter constants

$\dot{Q}$  = heat flux

The root  $\rho_{ck}$  is calculated from the equation

$$\sqrt{\rho_{ck}} = \frac{\dot{Q}}{T - T_i} \cdot \sqrt{\frac{2}{\pi}} \sqrt{t}$$

Root  $\rho_{ck}$  is calculated from the above equation where

$\dot{Q}$  = heat flux

T = current temperature

$T_i$  = initial model temperature

t = elapsed time

#### 3.4.4 Output Calculated Parameters

Six parameters are printed out by the BETA-ADCUS program, IDATA (x), QUE, TIME, TEMP and ROOT. QUE, once it has been calculated, is immediately printed for the entire series of test data. The other output parameters are printed each time the "DO" loop in Program BETA is executed. IDATA (x) is the input parameters from the infrared camera and the calorimeter. Values of x which are odd are

the infrared camera inputs while even values are for the calorimeter. TIME is the calculated value of the elapsed time. TEMP is the calculated value of temperature as calculated from the input of the infrared camera. ROOT is the calculated value of  $\sqrt{\rho c k}$ , the thermophysical parameter. Once the "DO" loop has completed 30 passes the program prints "STOP" and can be executed for another series of data points.

#### 3.4.5 Computer Program Listing

A complete listing of the program is contained in the attached Appendix D. Each line of code is explained in order to indicate the detailed operations of the routine.

## SECTION 4

### OPERATING PROCEDURE

The following procedure is recommended for performing tests with this system:

1. Prepare specimen and mount it into apparatus. Determine the desired test conditions such as heating rate and choose the proper heat guage.

Mount the heat guage and connect its output into the Channel 2 input of the Adacus. Much of this can be accomplished by referring to Reference 2, Section 8.

2. Turn on all electronic instruments and allow enough time for warm up. Both the heat guage and the infrared thermometer recorder output should be connected into their respective inputs to the Adacus before the Adacus is turned on in order to avoid possible damage to the input preamplifiers of the Adacus. Before operating any of the instruments read the original manufacturer's instruction manual.

3. Sight the infrared thermometer onto the specimen and tighten screws on its mount so that the radiometer head is secure. Adjust the emissivity control to approximately 0.96.

4. If the Phase-Change Detector is to be used, sight it onto the specimen and tighten the screws on its mount. Connect its output to a strip chart recorder with a 10 volt full scale input. In order to measure time accurately a strip chart recorder which has a time event marker should be used. If this type of recorder is not available a two channel recorder can be used where the second channel is fed by a pulse train with a known repetition rate.

Close the aperture on the Phase-Change Detector down to a minimum. Close the shutters and turn on the cooling water to the water filter and the thermophysical properties measurement apparatus. Activate the power to the heating lamps and adjust to the desired heating rate (see Reference 2). The detector should be sampling the radiation reflected from the top of the shutter. Open the aperture until the output becomes approximately 25% of full scale (2-3 volts). This should result in a signal reflected from the painted specimen which is 50% of full scale or larger. After the Phase-Change Detector has been adjusted the heating lamps may be shut down temporarily.

5. The next step is to set-up and program the Adacus Data Handling System. Set the MAX-TRACK-MIN Switch to TRACK on both channels. Set the  $\Delta T$  SEL Switch to the appropriate time base for the test. For the present computer program a value of 0.1 seconds should be selected for a total test time of 3 seconds and a value of 1 second should be selected for a total test time of 30 seconds.

A. THRESHOLD Value Selection - The threshold value is selected as follows:

i. Select the code value "01" on the CODE switches  
(switch in the up position = 1, down position = 0).

ii. Select the magnitude of the THRESHOLD value on the PROGRAM switches. For this test procedure all switches should be down.

iii. Depress the LOAD switch, and the information from the PROGRAM switches is transferred to the THRESHOLD

memory storage. The corresponding THRESHOLD value now appears on the THRESHOLD lights; none of the lights should be on.

iv. Repeat the above steps when the CHAN SEL switch is in both the channel 1 and the channel 2 position.

B. PRINTOUT SEL - INCREMENT SEL - The PRINTOUT SEL determines the criteria for generating a printout command to the computer. For this program we want a printout to occur after each successive  $\Delta T$  time increment. The INCREMENT SEL determines the magnitude change on the input signal that is required to cause an increment detector ( $\Delta$ ); for this case none of the increment values are programmed in since we are not increment detecting. The programming of PRINTOUT SEL - INCREMENT SEL proceeds as follows:

i. Select code "11" on the CODE switches.

ii. Select program switches directly below the "OR" and " $\Delta T$ " lights and position them to "ON" (up position). The remaining switches are positioned "OFF" (down position).

iii. Depress the LOAD switch. This transfers the information to the PRINTOUT SEL - INCREMENT SEL memory storage. The "OR" and " $\Delta T$ " lights should be on.

iv. Repeat the above steps when the CHAN SEL switch is in both the channel 1 and the channel 2 position.

C. Special Program Functions - This provides for programming either a remote start or a local reset control into the Adacus. In addition it provides for the THRESHOLD Value Selection for bits 9 through 12. The remote start function is programmed as follows:

- i. Select code "10" on the CODE switches.
- ii. Select program switch directly below the "A" light and position it to "ON" (up position). The remaining switches should be "OFF" (down position).
- iii. Depress the LOAD switch; the light below "A" should be on.
- iv. Repeat the above steps when the CHAN SEL switch is in the channel 1 and the channel 2 position.

As a final check only the "A", "OR", and " $\Delta T$ " program lights should be on when the CHAN SEL switch is in either the channel 1 or channel 2 positions.

Close the shutters on the Thermophysical Properties Measurement Apparatus. This opens the microswitch on the apparatus. Select the time position with the DATA/TIME switch (TIME light on). The lights on the Time/Data Register in the upper right position of the front panel should all be off with the CHAN SEL switch in either the 1 or 2 position.

Now open the shutter (close the microswitch). The Time/Data Register should immediately begin displaying a time word at a rate corresponding

to the position of the  $\Delta T$  SEL switch. Switch rapidly between channels 1 and 2 and note that the time word should be the same.

6. Open the shutters and sight through the radiometer head to insure that it is sampling the desired area of the specimen. With the specimen in thermal equilibrium measure the surface temperature of the specimen with a surface contacting thermometer (GFE). This temperature is teletyped into the computer as the initial model temperature,  $T_i$ . Adjust the emissivity control on the infrared thermometer control box so that the meter on the front panel reads the same temperature.

7. The program is now loaded into the computer. Check the computer to insure that the key is turned to the "ON" position and the teletype to the "LINE" position. Place tape number BII-10 into the tape reader and set the tape reader switch to "START." The following controls on the Hewlett Packard computer must be set. Push the "P" switch followed by "CLEAR DISPLAY." On the DISPLAY REGISTER key in the address of 7700 octal. The "S" switch is now pushed, followed by CLEAR DISPLAY. The following buttons are then pressed: LOADER ENABLE, INTERNAL PRESET, EXTERNAL PRESET, and RUN. The tape should be read into memory by the computer. The computer then halts with the octal code of 102077 in the DISPLAY REGISTER. This means that the program is ready to be executed. NOTE: Once this tape has been loaded into core memory unless it is inadvertently dumped it will remain in memory and will not have to be reloaded for every run. After a power failure the program tape should be reloaded.

8. After the program tape has been loaded, make sure that the shutters on the Thermophysical Properties Measurement Apparatus are closed and that the time word on the Time/Date Register of the Adacus is zero (no lights on).



Then on the computer press the "P" switch followed by the "CLEAR DISPLAY." Key into the DISPLAY REGISTER the octal address of 2. Press the "S" switch and the "CLEAR DISPLAY." Push the following switches: INTERNAL PRESET, EXTERNAL PRESET, and RUN. The computer will type the following line on the teletype:

INPUT THE DATA; FORMAT 4F9.4

The operator now enters the four required constants (see paragraph 3.4.1) for the program under the Format of 4F9.4. The RETURN and LINE FEED keys are pressed. If the operator makes an error on data entry the RUBOUT button should be pressed before the RETURN and LINE FEED buttons are pressed and the correct data should be entered on the next line. The computer at this point is waiting for the first flag from the Adacus.

9. The test is ready to be initiated. Turn on the cooling water to the water filter, shutters and the lamps. Activate the power to the lamps allowing a few seconds for their output to stabilize (see Reference 2). Open the shutters. This will initiate printout commands from the Adacus, and the temperature and heat rate data will be stored in the computer. While heating is occurring, monitor the temperature as indicated by the infrared thermometer. If the temperature reaches 500°F, turn the power to the lamps off. If the teleprinter begins printing out data then all thirty data points have been collected, and the power to the lamps can be turned off. The computer is now printing values of heating rate and  $\sqrt{\rho ck}$ .

10. If a new test is to be run much of the above procedure can be eliminated as long as the power to the electronics has not been shut off. If a

different heat guage is to be connected to the input of the Adacus, power should be shut off while the input is open circuited. The Adacus will then have to be reprogrammed.

## SECTION 5

### TEST RESULTS

#### 5.1 Phase-Change Detector

A "Stycast" specimen was coated with Tempilaq supplied by the government and the coated specimen was mounted in the thermophysical properties measurement apparatus. The Phase-Change Detector was sighted onto the center of the specimen and its output was fed to a Honeywell Model 1406 strip chart recorder. The water cooled shutter was left open prior to activating the heat lamps. The heat lamps were turned on and the resulting output of the Phase-Change Detector was plotted on strip chart paper. Figure 9 shows the results. Initially, two to three seconds are required for the lamps to reach thermal equilibrium. During the time period from three seconds to six seconds the reflected radiation remained relatively constant, indicating that the heat flux from the lamps had stabilized to a constant rate. After about six and one half (6 1/2) seconds the phase-change coating was visually observed to begin melting in the area sampled by the Phase-Change Detector as indicated by the first marker. At approximately nine and one half (9 1/2) seconds the entire area had liquified as indicated by the second marker. From 10 seconds to 13 seconds the coated specimen was observed to rapidly change to a black color.

This test has indicated the warm-up nature of the heat lamps and has shown that the Phase-Change Detector is a very sensitive instrument for detecting the melt temperature of phase-change coatings.

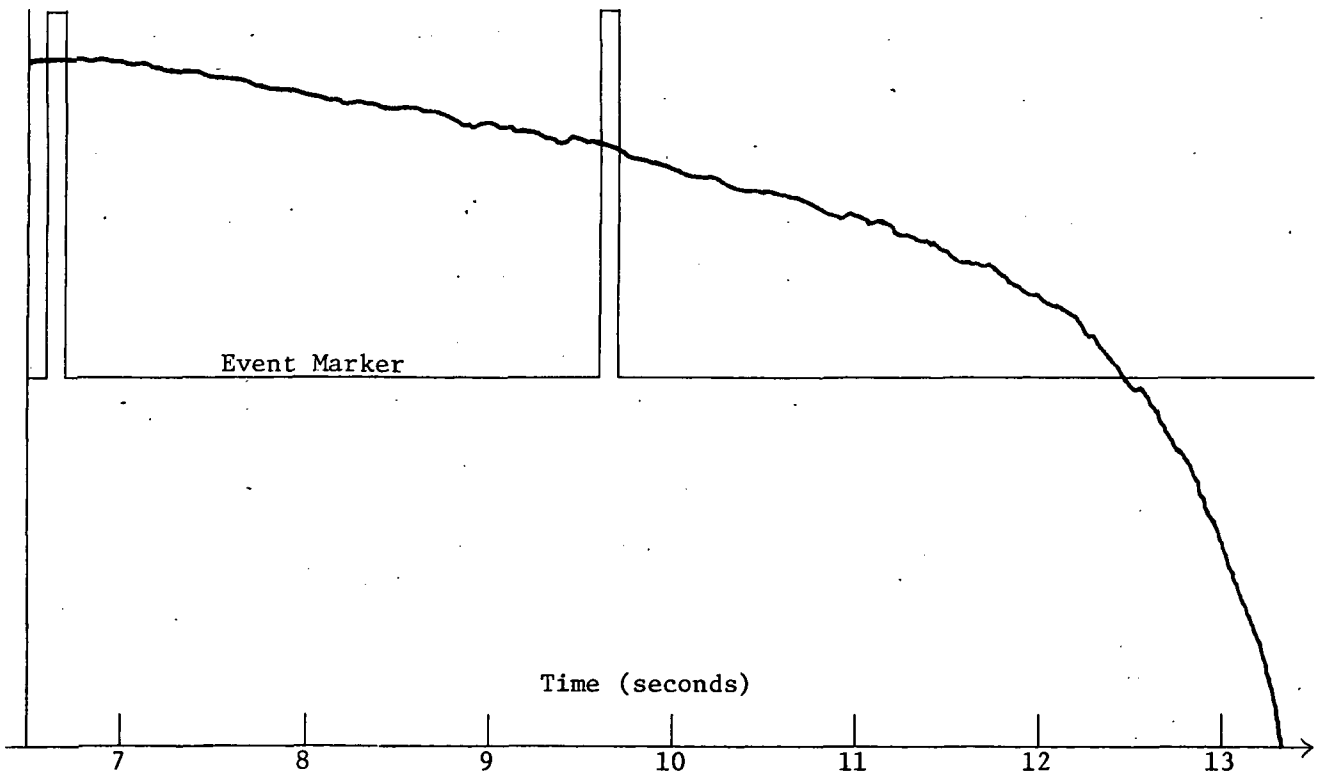
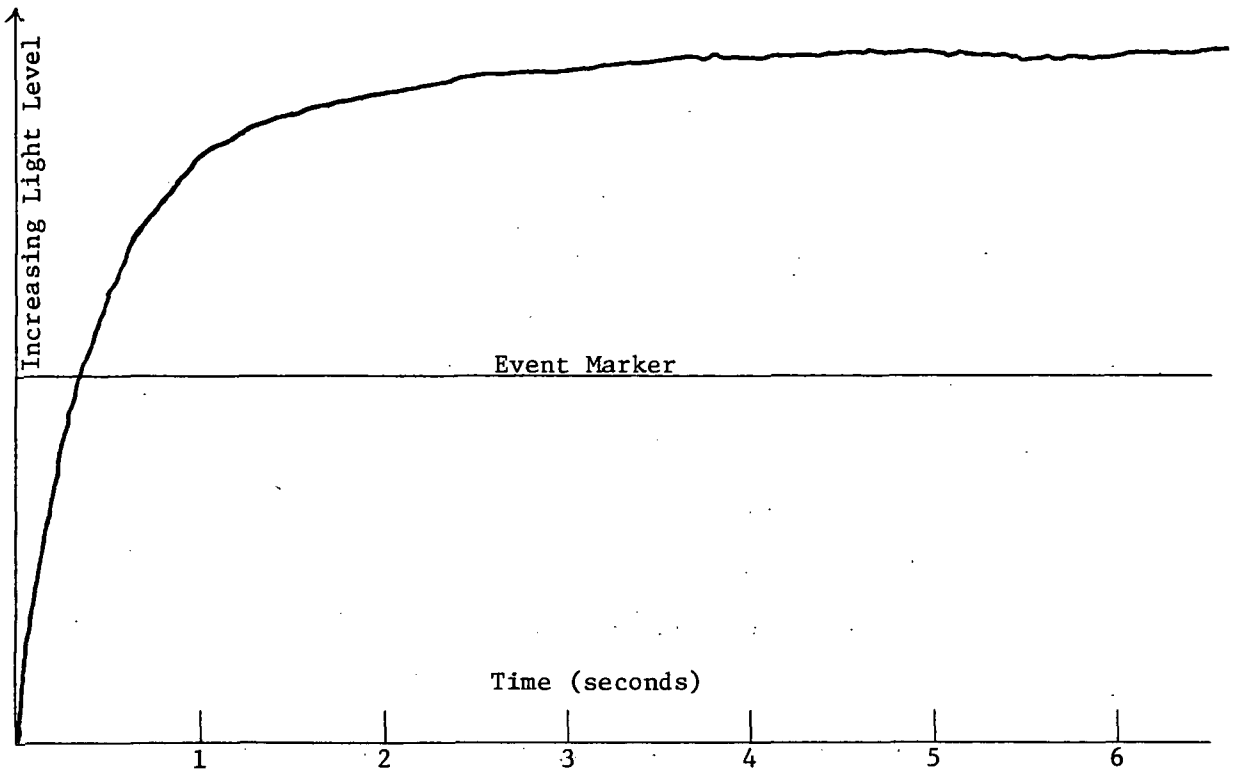


Figure 9. Plot of Phase-Change Detector Output

## 5.2 Thermophysical Properties Measurements

Measurements of  $\sqrt{\rho c k}$  were obtained for a sample of Stycast plastic supplied by NASA in order to verify the computer program and the overall operation of the system. An uncoated specimen and a 0.08 inch thick heat guage were mounted in the specimen holder. The operating procedures outlined in Section 4 were followed except for the measurement of the initial temperature. After the water cooled shutters were closed, we found that the specimen temperature was lowered because of the lower temperature of the cooling water. As a result the temperature of the exit cooling water was measured and teletyped into the computer as the initial specimen temperature. Four data runs were taken all at the same input power setting to the heat lamps. For each run the computer program was set up to record thirty data points at constant increments of one (1) second. The heating rate was averaged over the last twenty-five data points and the results for the four runs were 2.791, 2.786, 2.826, and 2.760 Btu/ft<sup>2</sup>-sec.

The results are shown in Tables 3, 4, 5, and 6. The second column lists the register counts from the Adacus data handling system. The odd numbered entries are from the infrared thermometer channel, and the even numbered entries are from the heat guage channel. The last three columns are the elapsed time, the specimen temperature as measured by the infrared thermometer, and the corresponding calculated value of  $\sqrt{\rho c k}$ . The initial temperature, heat gauge constants, and the calculated value of the heating rate are shown at the top of the print-out sheet.

Inspection of the data shows that the last few entries of each run indicate that  $\sqrt{\rho c k}$  varies from about 0.072 to 0.076 Btu/ft<sup>2</sup>-°F-(sec.)<sup>1/2</sup> or about  $\pm 2.7\%$  variation. The variation at the beginning of the runs are somewhat larger. This

can be explained by the large variation in temperature rise due to a large variation in heating rate at the beginning (see heat guage register counts at the beginning of column 2). The initial radiometer temperature in Tables 4 and 5 are larger than the other two runs and it remains larger throughout these two runs resulting in lower values of  $\sqrt{\rho ck}$ . These two runs (Tables 4 and 5) do not show a corresponding increase in the computed value of the heating rate. It is recommended for future work that studies be performed to determine if the heating rate is constant throughout the run and the effects of any variation on the accuracy of the measurements. This can be accomplished quite easily from the heating rate data shown in column 2 of the data printout.

Another potential source of error in these preliminary measurements is the method of measuring the initial temperature. Since the specimen temperature is reduced below ambient by the cooled shutters, it is recommended that the initial temperature be measured directly by the heat guage thermocouple.

TABLE 3

Printout of  $\sqrt{\rho c k}$  Versus Specimen Temperature - Test Number 1

59.0000 0.3250 0.1144 10.0000

QUE= 2.791

IDATA 1	.520000E+02			
IDATA 2	.600000E+01			
		TIME	TEMP	ROOT
		1.000	111.816	.060
IDATA 3	.700000E+02			
IDATA 4	.860000E+02			
		2.000	126.291	.066
IDATA 5	.890000E+02			
IDATA 6	.178000E+03			
		3.000	139.943	.067
IDATA 7	.102000E+03			
IDATA 8	.261000E+03			
		4.000	148.556	.070
IDATA 9	.116000E+03			
IDATA10	.344000E+03			
		5.000	157.302	.072
IDATA11	.129000E+03			
IDATA12	.421000E+03			
		6.000	165.006	.073
IDATA13	.142000E+03			
IDATA14	.500000E+03			
		7.000	172.363	.074
IDATA15	.154000E+03			
IDATA16	.584000E+03			
		8.000	178.884	.074
IDATA17	.168000E+03			
IDATA18	.665000E+03			
		9.000	186.202	.074
IDATA19	.181000E+03			
IDATA20	.745000E+03			
		10.000	192.747	.075
IDATA21	.193000E+03			
IDATA22	.826000E+03			
		11.000	198.596	.075
IDATA23	.206000E+03			
IDATA24	.905000E+03			
		12.000	204.743	.075
IDATA25	.220000E+03			
IDATA26	.983000E+03			
		13.000	211.162	.075

TABLE 3 (Cont'd)

I DATA27	.233000E+03			
I DATA28	.106300E+04	14.000	216.951	.075
I DATA29	.248000E+03			
I DATA30	.114100E+04	15.000	222.640	.075
I DATA31	.260000E+03			
I DATA32	.122000E+04	16.000	227.624	.075
I DATA33	.274000E+03			
I DATA34	.129300E+04	17.000	233.093	.075
I DATA35	.286000E+03			
I DATA36	.136800E+04	18.000	237.531	.075
I DATA37	.301000E+03			
I DATA38	.144300E+04	19.000	242.801	.075
I DATA39	.316000E+03			
I DATA40	.152000E+04	20.000	247.808	.075
I DATA41	.329000E+03			
I DATA42	.159100E+04	21.000	251.962	.075
I DATA43	.344000E+03			
I DATA44	.166600E+04	22.000	256.568	.075
I DATA45	.357000E+03			
I DATA46	.174000E+04	23.000	260.413	.075
I DATA47	.371000E+03			
I DATA48	.180700E+04	24.000	264.419	.075
I DATA49	.385000E+03			
I DATA50	.187700E+04	25.000	268.297	.075
I DATA51	.399000E+03			
I DATA52	.194800E+04	26.000	272.059	.075
I DATA53	.414000E+03			
I DATA54	.202200E+04	27.000	275.972	.076
I DATA55	.430000E+03			
I DATA56	.209200E+04	28.000	280.023	.076
I DATA57	.446000E+03			
I DATA58	.215700E+04	29.000	283.958	.076
I DATA59	.459000E+03			
I DATA60	.222100E+04	30.000	287.076	.076
STOP				



TABLE 4

Printout of  $\sqrt{pck}$  Versus Specimen Temperature - Test Number 2

59.9000 0.3250 0.1144 10.0000

QUE= 2.786

IDATA 1	.620000E+02			
IDATA 2	.300000E+02			
		TIME	TEMP	ROOT
		1.000	120.075	.052
IDATA 3	.840000E+02			
IDATA 4	.115000E+03			
		2.000	136.484	.058
IDATA 5	1.000000E+02			
IDATA 6	.199000E+03			
		3.000	147.264	.062
IDATA 7	.114000E+03			
IDATA 8	.282000E+03			
		4.000	156.083	.065
IDATA 9	.130000E+03			
IDATA10	.360000E+03			
		5.000	165.583	.067
IDATA11	.142000E+03			
IDATA12	.441000E+03			
		6.000	172.363	.069
IDATA13	.157000E+03			
IDATA14	.523000E+03			
		7.000	180.478	.069
IDATA15	.172000E+03			
IDATA16	.603000E+03			
		8.000	188.240	.069
IDATA17	.184000E+03			
IDATA18	.687000E+03			
		9.000	194.226	.070
IDATA19	.198000E+03			
IDATA20	.767000E+03			
		10.000	200.983	.071
IDATA21	.213000E+03			
IDATA22	.846000E+03			
		11.000	207.973	.071
IDATA23	.226000E+03			
IDATA24	.924000E+03			
		12.000	213.854	.071
IDATA25	.241000E+03			
IDATA26	.100600E+04			
		13.000	220.438	.071

TABLE 4 (Cont'd)

I DATA27	.255000E+03			
I DATA28	.108200E+04	14.000	225.584	.071
I DATA29	.268000E+03			
I DATA30	.115800E+04	15.000	230.791	.071
I DATA31	.282000E+03			
I DATA32	.123600E+04	16.000	236.075	.071
I DATA33	.297000E+03			
I DATA34	.131000E+04	17.000	241.423	.071
I DATA35	.311000E+03			
I DATA36	.138900E+04	18.000	246.166	.072
I DATA37	.325000E+03			
I DATA38	.146100E+04	19.000	250.701	.072
I DATA39	.338000E+03			
I DATA40	.153700E+04	20.000	254.748	.072
I DATA41	.353000E+03			
I DATA42	.161000E+04	21.000	259.243	.072
I DATA43	.369000E+03			
I DATA44	.168100E+04	22.000	263.855	.072
I DATA45	.385000E+03			
I DATA46	.175300E+04	23.000	268.297	.072
I DATA47	.401000E+03			
I DATA48	.182400E+04	24.000	272.588	.073
I DATA49	.414000E+03			
I DATA50	.189400E+04	25.000	275.972	.073
I DATA51	.430000E+03			
I DATA52	.196800E+04	26.000	280.023	.073
I DATA53	.444000E+03			
I DATA54	.203600E+04	27.000	283.472	.073
I DATA55	.458000E+03			
I DATA56	.210500E+04	28.000	286.839	.073
I DATA57	.474000E+03			
I DATA58	.216300E+04	29.000	290.593	.073
I DATA59	.490000E+03			
I DATA60	.223300E+04	30.000	294.254	.074
STOP				

TABLE 5

Printout of  $\sqrt{\rho c k}$  Versus Specimen Temperature - Test Number 3

59.9000 0.3250 0.1144 10.0000

QUE= 2.826

IDATA 1	.660000E+02			
IDATA 2	.450000E+02			
		TIME	TEMP	ROOT
		1.000	123.223	.050
IDATA 3	.850000E+02			
IDATA 4	.128000E+03			
		2.000	137.183	.058
IDATA 5	.101000E+03			
IDATA 6	.212000E+03			
		3.000	147.912	.063
IDATA 7	.118000E+03			
IDATA 8	.295000E+03			
		4.000	158.512	.065
IDATA 9	.131000E+03			
IDATA10	.380000E+03			
		5.000	166.159	.067
IDATA11	.145000E+03			
IDATA12	.462000E+03			
		6.000	174.017	.069
IDATA13	.160000E+03			
IDATA14	.548000E+03			
		7.000	182.057	.069
IDATA15	.175000E+03			
IDATA16	.629000E+03			
		8.000	189.755	.070
IDATA17	.187000E+03			
IDATA18	.710000E+03			
		9.000	195.694	.071
IDATA19	.202000E+03			
IDATA20	.793000E+03			
		10.000	202.872	.071
IDATA21	.215000E+03			
IDATA22	.872000E+03			
		11.000	208.892	.071
IDATA23	.230000E+03			
IDATA24	.953000E+03			
		12.000	215.629	.071
IDATA25	.245000E+03			
IDATA26	.103500E+04			
		13.000	222.161	.071

TABLE 5 (Cont'd)

I DATA27	.259000E+03			
I DATA28	.111300E+04	14.000	227.220	.071
I DATA29	.274000E+03			
I DATA30	.118700E+04	15.000	233.093	.071
I DATA31	.287000E+03			
I DATA32	.126900E+04	16.000	237.891	.072
I DATA33	.301000E+03			
I DATA34	.134500E+04	17.000	242.801	.072
I DATA35	.315000E+03			
I DATA36	.142100E+04	18.000	247.482	.072
I DATA37	.333000E+03			
I DATA38	.149700E+04	19.000	253.209	.072
I DATA39	.346000E+03			
I DATA40	.157400E+04	20.000	257.168	.072
I DATA41	.362000E+03			
I DATA42	.165000E+04	21.000	261.859	.072
I DATA43	.377000E+03			
I DATA44	.172200E+04	22.000	266.096	.073
I DATA45	.391000E+03			
I DATA46	.179400E+04	23.000	269.923	.073
I DATA47	.408000E+03			
I DATA48	.186400E+04	24.000	274.421	.073
I DATA49	.421000E+03			
I DATA50	.193700E+04	25.000	277.759	.073
I DATA51	.437000E+03			
I DATA52	.200900E+04	26.000	281.758	.073
I DATA53	.452000E+03			
I DATA54	.207700E+04	27.000	285.406	.074
I DATA55	.466000E+03			
I DATA56	.214600E+04	28.000	288.728	.074
I DATA57	.481000E+03			
I DATA58	.221300E+04	29.000	292.206	.074
I DATA59	.497000E+03			
I DATA60	.228000E+04	30.000	295.828	.074
STOP				

TABLE 6

Printout of  $\sqrt{\rho}ck$  Versus Specimen Temperature - Test Number 4

59.0000 0.3250 0.1144 10.0000

QUE= 2.760

IDATA 1	.500000E+02			
IDATA 2	.300000E+01			
		TIME	TEMP	ROOT
		1.000	110.038	.061
IDATA 3	.690000E+02			
IDATA 4	.830000E+02			
		2.000	125.531	.066
IDATA 5	.850000E+02			
IDATA 6	.165000E+03			
		3.000	137.183	.069
IDATA 7	1.000000E+02			
IDATA 8	.249000E+03			
		4.000	147.264	.071
IDATA 9	.113000E+03			
IDATA10	.329000E+03			
		5.000	155.470	.072
IDATA11	.126000E+03			
IDATA12	.410000E+03			
		6.000	163.261	.073
IDATA13	.141000E+03			
IDATA14	.492000E+03			
		7.000	171.809	.073
IDATA15	.153000E+03			
IDATA16	.573000E+03			
		8.000	178.350	.074
IDATA17	.167000E+03			
IDATA18	.657000E+03			
		9.000	185.689	.074
IDATA19	.180000E+03			
IDATA20	.734000E+03			
		10.000	192.252	.074
IDATA21	.194000E+03			
IDATA22	.815000E+03			
		11.000	199.076	.074
IDATA23	.206000E+03			
IDATA24	.890000E+03			
		12.000	204.743	.074
IDATA25	.220000E+03			
IDATA26	.967000E+03			
		13.000	211.162	.074

TABLE 6 (Cont'd)

I DATA27	.232000E+03			
I DATA28	.104300E+04			
		14.000	216.511	.074
I DATA29	.247000E+03			
I DATA30	.112100E+04			
		15.000	222.210	.074
I DATA31	.260000E+03			
I DATA32	.119800E+04			
		16.000	227.624	.074
I DATA33	.273000E+03			
I DATA34	.127300E+04			
		17.000	232.714	.074
I DATA35	.286000E+03			
I DATA36	.134600E+04			
		18.000	237.531	.074
I DATA37	.302000E+03			
I DATA38	.142100E+04			
		19.000	243.143	.074
I DATA39	.313000E+03			
I DATA40	.149700E+04			
		20.000	246.826	.074
I DATA41	.329000E+03			
I DATA42	.156700E+04			
		21.000	251.962	.074
I DATA43	.343000E+03			
I DATA44	.163900E+04			
		22.000	256.266	.074
I DATA45	.358000E+03			
I DATA46	.171100E+04			
		23.000	260.704	.074
I DATA47	.370000E+03			
I DATA48	.178100E+04			
		24.000	264.137	.074
I DATA49	.385000E+03			
I DATA50	.185100E+04			
		25.000	268.297	.075
I DATA51	.399000E+03			
I DATA52	.192000E+04			
		26.000	272.059	.075
I DATA53	.413000E+03			
I DATA54	.198900E+04			
		27.000	275.715	.075
I DATA55	.429000E+03			
I DATA56	.205700E+04			
		28.000	279.773	.075
I DATA57	.443000E+03			
I DATA58	.212100E+04			
		29.000	283.229	.075
I DATA59	.457000E+03			
I DATA60	.218500E+04			
		30.000	286.601	.075
STOP				

## SECTION 6

### CONCLUSIONS AND RECOMMENDATIONS

An electronic system has been developed for measuring the thermophysical parameters of wind tunnel models. The system includes an infrared thermometer for measuring specimen surface temperature at high speeds, a data handling system for converting the data to digital form, and a small computer for processing the data. An optical detector has been developed for use with phase-change coatings in order to determine the time that it takes the specimen to increase from initial to melt temperature.

A complete program has been developed and measurements were taken on Stycast specimens supplied by NASA. The results show that the system can provide accurate and fast measurements of  $\sqrt{\rho ck}$ . The small computer provides for the flexibility of performing a variety of heat transfer measurements. Also studies can be performed to improve the experimental procedures and indicate source of error in the measurement of  $\sqrt{\rho ck}$ .

It is recommended that the heating rate curve be measured. A computer program can be written to print out the first derivative of the heat gauge temperature as a function of time. The initial rise of the heating rate step function can be studied by increasing the sampling rate of the Adacus data handling system to 0.01 seconds. Also, the method for measuring the initial temperature should be carefully considered.

#### REFERENCES

1. R. A. Jones and J. L. Hunt, "Use of Fusible Temperature Indicators for Obtaining Quantitative Aerodynamic Heat-Transfer Data," NASA TR R-230, February 1966.
2. R. Romanowski and I. H. Steinberg, "Development of an Apparatus to Measure Thermophysical Properties of Wind Tunnel Heat Transfer Models." NASA CR-2434, 1974. (Grumman Final Report, Contract No. NAS1-11537.)
3. M. A. Bramson, "Infrared Radiation - A Handbook for Applications," Plenum Press, New York, 1968.
4. J. A. Curcio and C. C. Petty, Journal of the Optical Society of America, 41, No. 5, pp 302-304, May 1951.

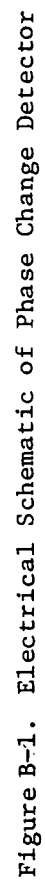


TABLE A-1  
Temperature Versus Output for Barnes Model IT-7E  
Infrared Thermometer

Temperature (°F)	Radiance (Watts/Cm <sup>2</sup> -Ster.)	Radiometer Output (Volts)
50.0	0.92590E-03	0.000
55.0	0.99402E-03	0.007
60.0	0.10659E-02	0.015
65.0	0.11413E-02	0.023
70.0	0.12218E-02	0.032
75.0	0.13061E-02	0.041
80.0	0.13947E-02	0.051
85.0	0.14880E-02	0.061
90.0	0.15859E-02	0.072
95.0	0.16887E-02	0.083
100.0	0.17966E-02	0.095
105.0	0.19097E-02	0.107
110.0	0.20282E-02	0.120
115.0	0.21522E-02	0.134
120.0	0.22820E-02	0.148
125.0	0.24177E-02	0.163
130.0	0.25594E-02	0.179
135.0	0.27075E-02	0.195
140.0	0.28620E-02	0.212
145.0	0.30231E-02	0.229
150.0	0.31911E-02	0.248
155.0	0.33661E-02	0.267
160.0	0.35483E-02	0.287
165.0	0.37380E-02	0.308
170.0	0.39353E-02	0.330
175.0	0.41404E-02	0.352
180.0	0.43536E-02	0.375
185.0	0.45750E-02	0.400
190.0	0.48049E-02	0.425
195.0	0.50435E-02	0.451
200.0	0.52910E-02	0.478
205.0	0.55477E-02	0.506
210.0	0.58137E-02	0.536
215.0	0.60893E-02	0.566
220.0	0.63747E-02	0.597
225.0	0.66702E-02	0.629
230.0	0.69759E-02	0.663
235.0	0.72922E-02	0.698
240.0	0.76193E-02	0.734
245.0	0.79574E-02	0.771
250.0	0.83068E-02	0.809
255.0	0.86676E-02	0.848
260.0	0.90403E-02	0.889
265.0	0.94250E-02	0.932
270.0	0.98221E-02	0.975

TABLE A-1  
Temperature Versus Output for Barnes Model IT-7E  
Infrared Thermometer (Cont'd)

Temperature (°F)	Radiance (Watts/Cm <sup>2</sup> -Ster.)	Radiometer Output (Volts)
275.0	0.10231E-01	1.020
280.0	0.10654E-01	1.066
285.0	0.11089E-01	1.114
290.0	0.11538E-01	1.163
295.0	0.12001E-01	1.214
300.0	0.12477E-01	1.266
305.0	0.12968E-01	1.320
310.0	0.13473E-01	1.375
315.0	0.13993E-01	1.433
320.0	0.14528E-01	1.491
325.0	0.15078E-01	1.552
330.0	0.15645E-01	1.614
335.0	0.16227E-01	1.677
340.0	0.16825E-01	1.743
345.0	0.17440E-01	1.811
350.0	0.18072E-01	1.880
355.0	0.18721E-01	1.951
360.0	0.19387E-01	2.024
365.0	0.20072E-01	2.099
370.0	0.20774E-01	2.176
375.0	0.21495E-01	2.255
380.0	0.22235E-01	2.336
385.0	0.22994E-01	2.420
390.0	0.23772E-01	2.505
395.0	0.24570E-01	2.592
400.0	0.25388E-01	2.682
405.0	0.26227E-01	2.774
410.0	0.27087E-01	2.868
415.0	0.27967E-01	2.965
420.0	0.28869E-01	3.064
425.0	0.29793E-01	3.165
430.0	0.30740E-01	3.269
435.0	0.31708E-01	3.375
440.0	0.32700E-01	3.484
445.0	0.33715E-01	3.595
450.0	0.34753E-01	3.709
455.0	0.35816E-01	3.826
460.0	0.36903E-01	3.945
465.0	0.38014E-01	4.067
470.0	0.39151E-01	4.191
475.0	0.40313E-01	4.319
480.0	0.41502E-01	4.449
485.0	0.42716E-01	4.582
490.0	0.43957E-01	4.718
495.0	0.45225E-01	4.857
500.0	0.46520E-01	4.999



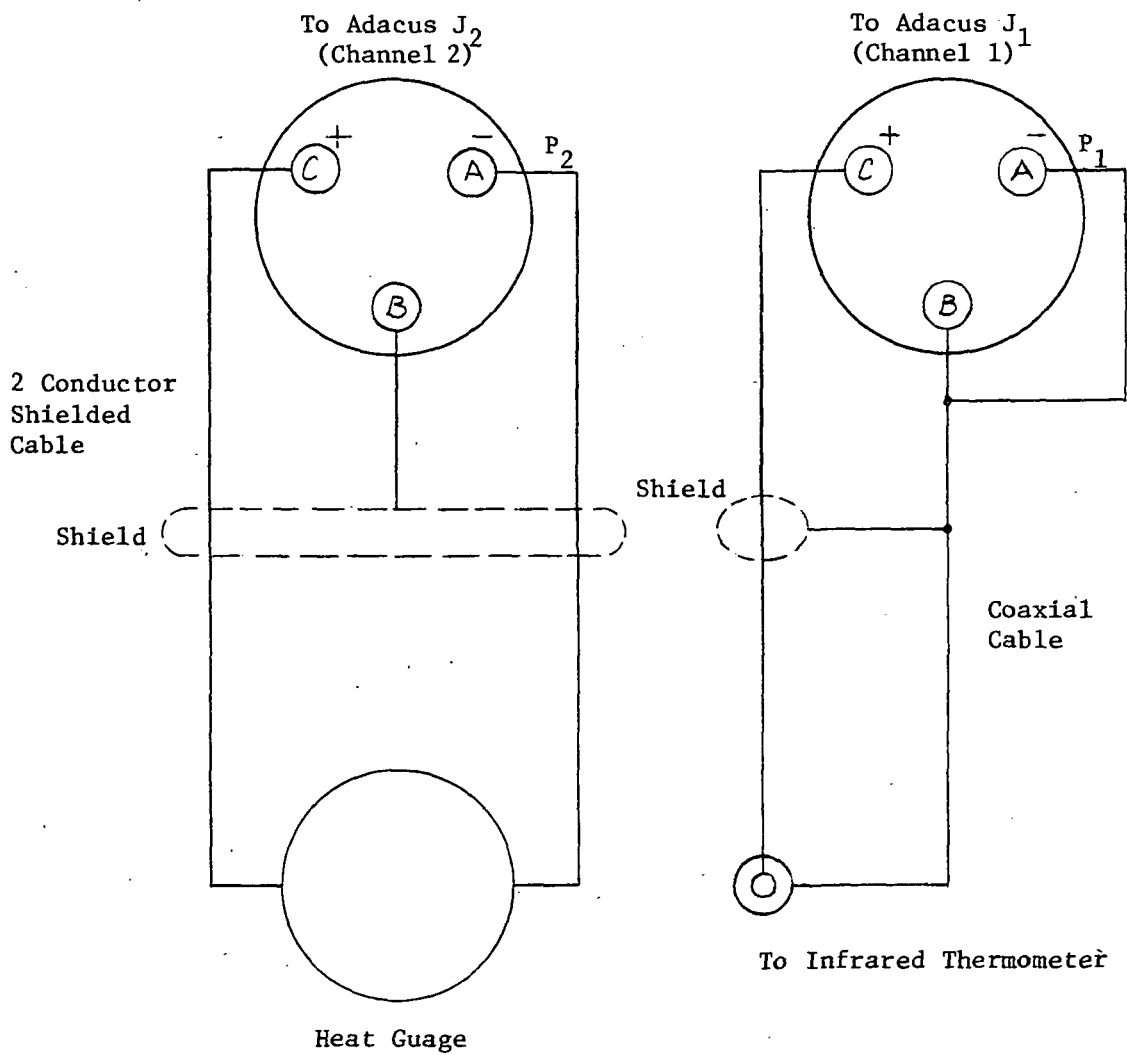
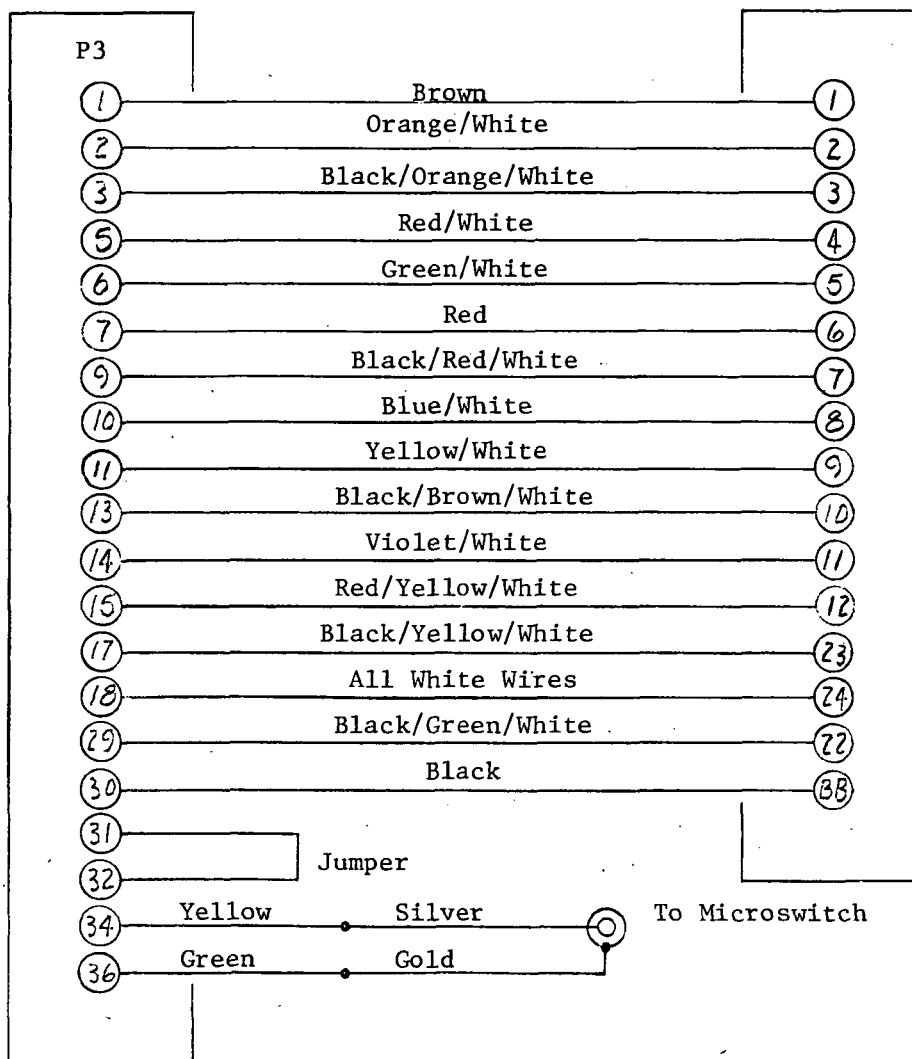


Figure C-1. Diagram of Input Cables to Adacus, Channels 1 and 2

To ADACUS (J3)  
AMPHENOL 57-30360

To HEWLETT PACKARD 2100A  
5060-8339

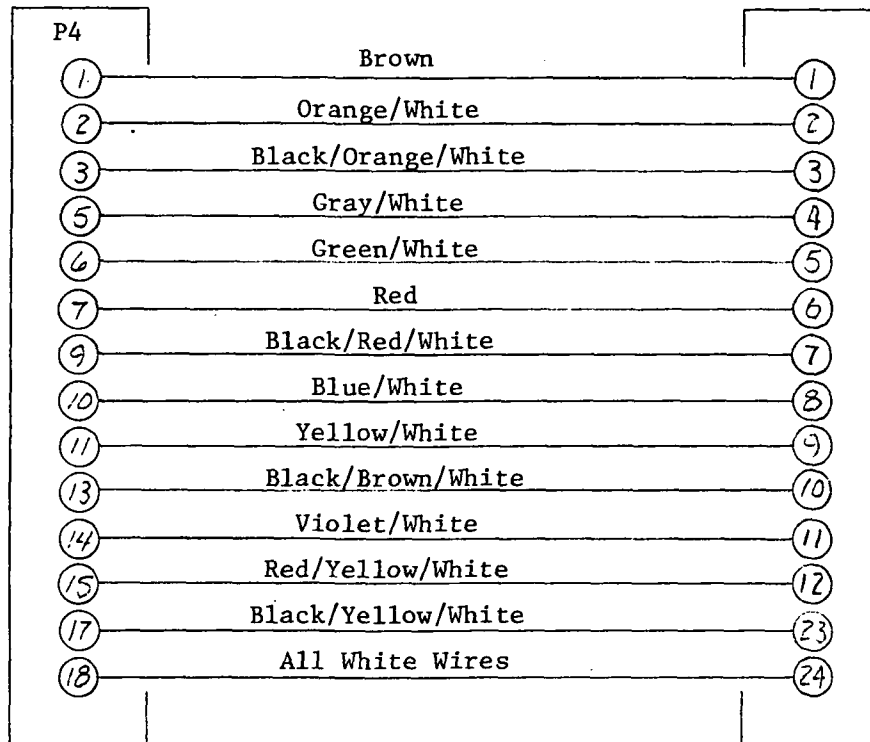


Cable: HP 8120-1846

Figure C-2. Diagram of Interface Cable of Channel 1 Data (Infrared Thermometer) from Adacus to HP Computer

To ADACUS (J4)  
AMPHENOL 57-30360

To HEWLETT PACKARD 2100A  
5060-8339



Cable HP 8120-1846

Figure C-3. Diagram of Interface Cable of Channel 2  
Data (Heat Gauge) from Adacus to HP Computer.

## APPENDIX D

### INTRODUCTION

This appendix contains the source language listing for programs BETA and ADCUS. Program BETA is a Fortran language program beginning on page D-2. Program ADCUS begins on page D-4 and is an Assembler language program.

The detailed description follows the program listings and flow charts. The Fortran language program will be referenced from the program statement numbers in the following manner: 10 + 2 or 10 - 4. This means that the statement is either following the referenced statement (+) or before the referenced statement (-). The left most column in the Assembler program is the line number of each operation. Each line, or set of lines, will be discussed in the following sections. Flow charts of the programs follow their listings.

PROGRAM BETA - FORTRAN SOURCE LANGUAGE

```

FTN,B,L,A,T
PROGRAM BETA
C
C PROGRAM BETA, ALONG WITH SUBROUTINE ADCUS, LOADS BINARY DATA AND
C CALCULATES THE PARAMETERS, TIME, HEATING RATE (QUE), AND THE THERMO-
C PHYSICAL PARAMETER, SQUARE ROOT PCK (ROOT). THE MAIN PROGRAM BETA
C IS UTILIZED TO CALCULATE THE DATA AND OUTPUT THE RESULTS; WHILE
C SUBROUTINE ADCUS IS USED TO LOAD THE DATA FROM THE ADACUS A TO D
C CONVERTER.
C
C DIMENSION CONS(4),IDATA(60)
C
C REQUEST INPUT DATA (TEMPERATURE, CALORIMETER, AND TIME CONSTANTS).
C
C WRITE(2,10)
C 10 FORMAT("INPUT THE DATA; FORMAT 4F9.4")
C
C INPUT THE CONSTANTS.
C
C READ(1,20)(CONS(J),J=1,4)
C 20 FORMAT(4F9.4)
C
C SUBROUTINE ADCUS IS CALLED AND EXECUTED.
C
C CALL ADCUS(IDATA)
C N=1
C TIME=0.0
C A1=0.1
C CONST=A1*CONS(4)
C
C CALCULATE QUE, TEMPERATURE, TIME. AND ROOTS.
C
C QUET=(FLOAT(IDATA(60))-FLOAT(IDATA(10)))*(CONS(2)*CONS(3))
C QUE=QUET/((30.0*CONST)-(5.0*CONST))
C WRITE(2,25)QUE
C 25 FORMAT(2/,"QUE=",F9.3,3/)
C DO 65 I=1,30
C TEMPR=FLOAT(IDATA(N))
C WRITE(2,30)N,TEMPR
C 30 FORMAT("IDATA"12,5X,E12.6)
C IF (TEMPR-245.76) 33,33,35
C 33 TEMP=(13.77*(TEMPR+12.57)**.5)+1.166
C GO TO 37
C 35 TEMP=(8.28*(TEMPR-154.58)**.5)+142.61

```



```

37 TIME=TIME+CONST
   N=N+1
   DQ=FLOAT(IDATA(N))
   WRITE(2,40)N,DQ
40  FORMAT("IDATA",I2,5X,E12.6)
   ROOT=(1.13*QUE)*(((TIME)**0.5)/(TEMP-CONS(1)))
   IF(N-2)45,45,55
45  WRITE(2,50)
50  FORMAT(28X,"TIME",8X,"TEMP",8X,"ROOT")
   GO TO 55
55  WRITE(2,60)TIME,TEMP,ROOT
60  FORMAT(25X,F9.3,3X,F9.3,3X,F9.3)
   N=N+1
65  CONTINUE
   END
   ENDS

```

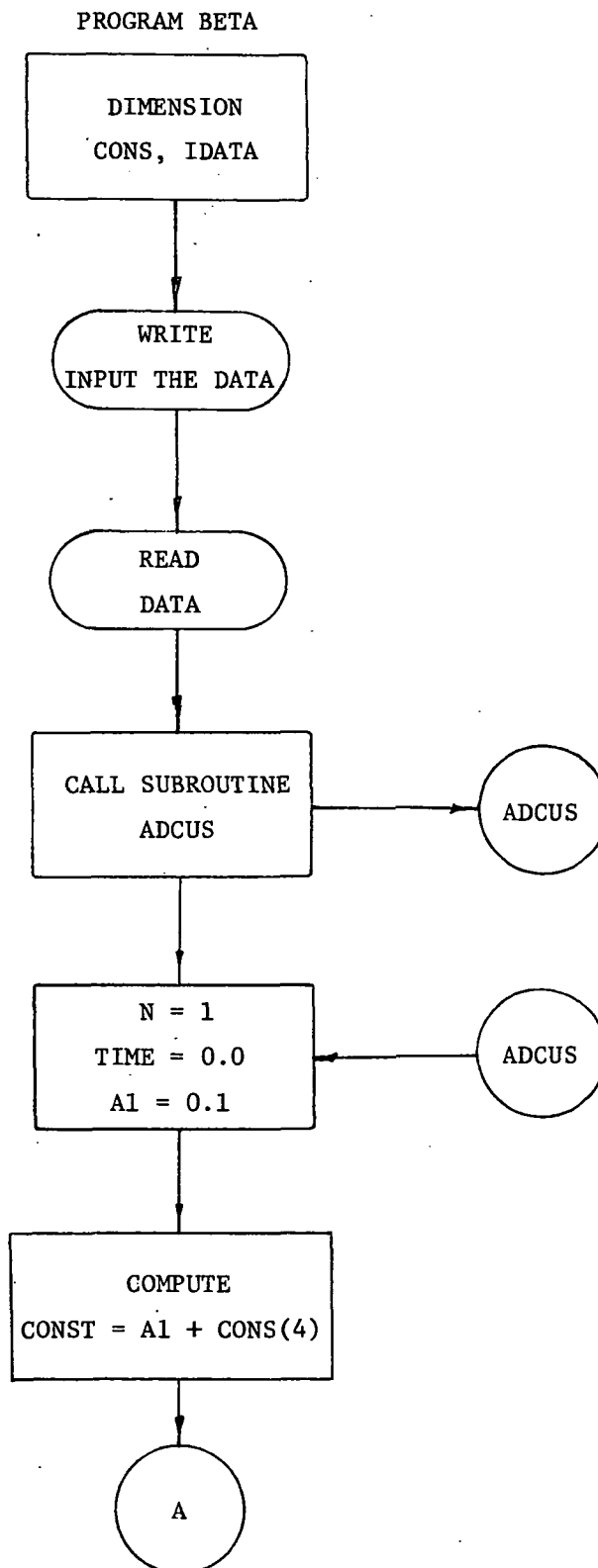
PROGRAM ADCUS - ASSEMBLER SOURCE LANGUAGE

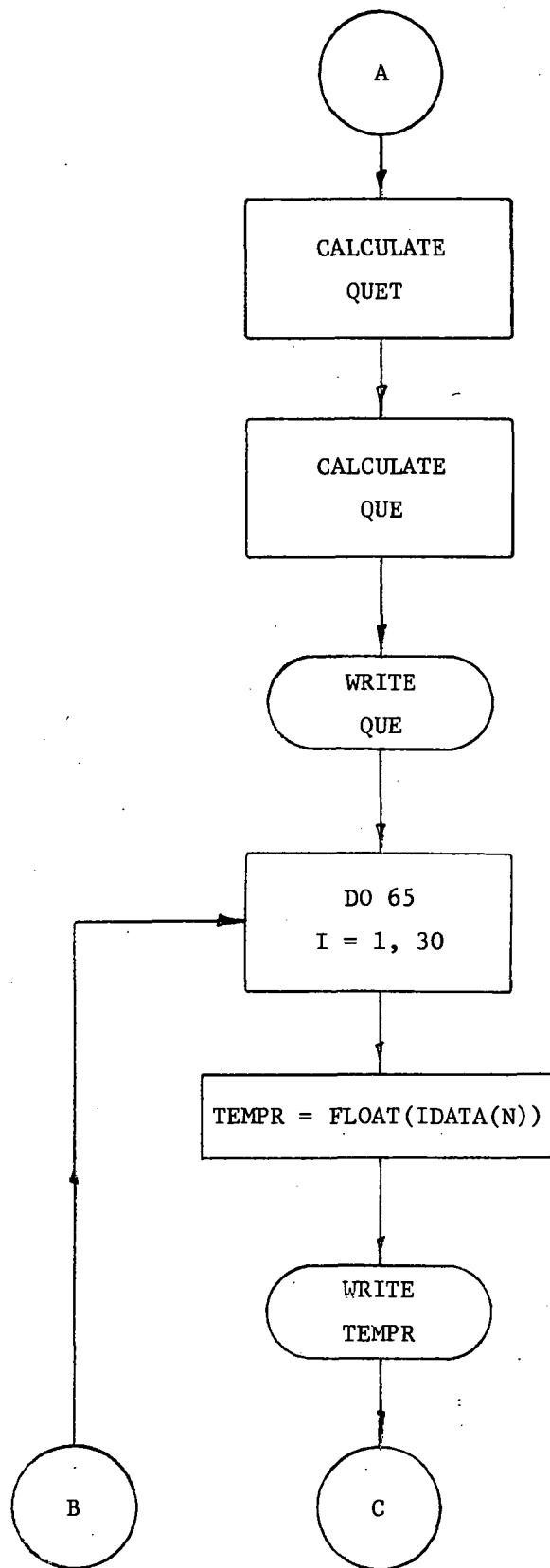
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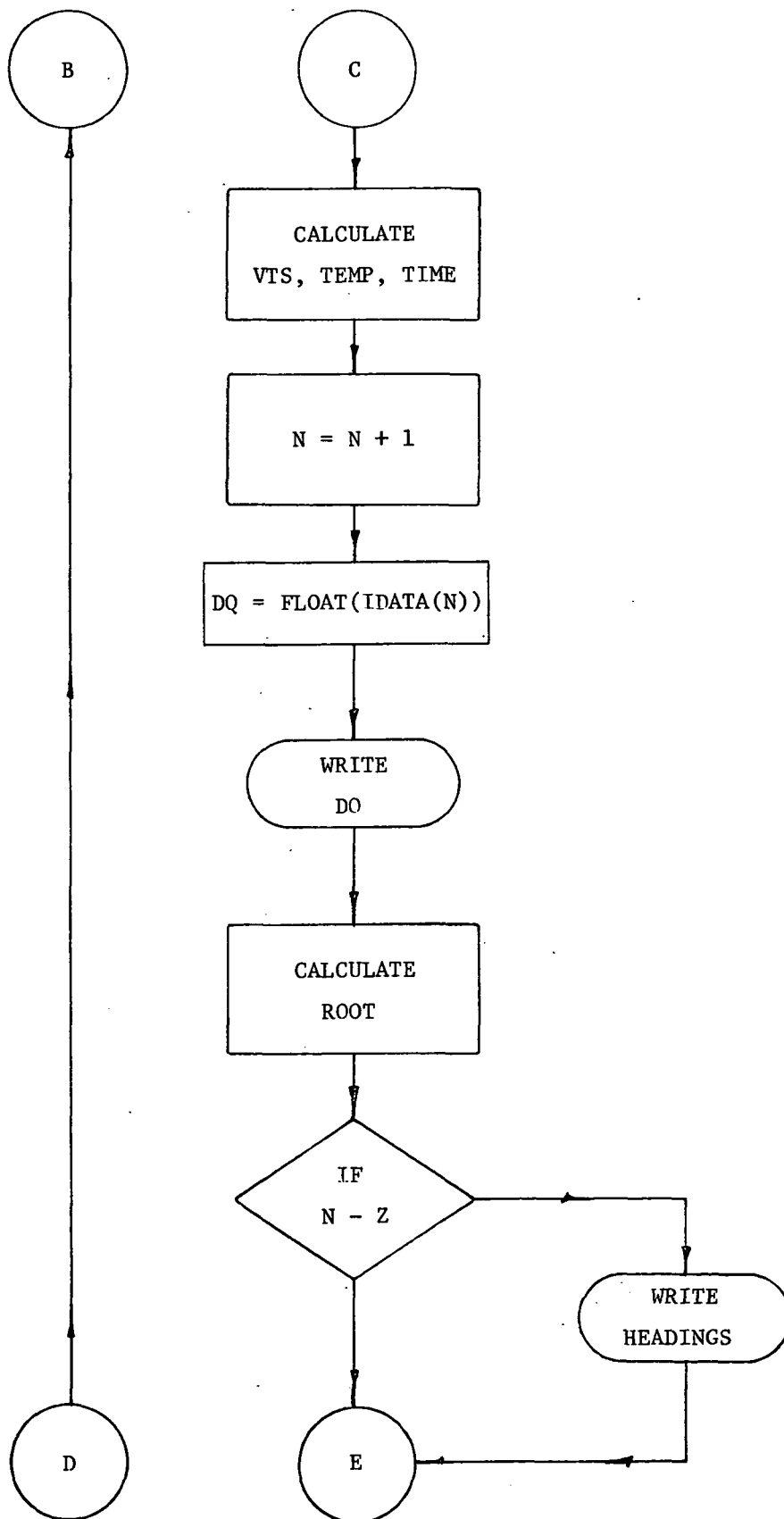
0001          ASMB,R,B,L,T
0002 00000          NAM ADCUS
0003          ENT ADCUS
0004          EXT .ENTR
0005 00000 000000 IDATA BSS 60
0006 00074 000000 ADCUS NOP
0007 00075 016001X JSB .ENTR
0008 00076 000000R DATA DEF IDATA
0009 00077 062134R LDA N30
0010 00100 072133R STA COUNT
0011 00101 000000 INPUT NOP
0012 00102 016113R JSB INONE
0013 00103 172000R STA IDATA,I
0014 00104 036000R ISZ IDATA
0015 00105 016123R JSB INTWO
0016 00106 172000R STA IDATA,I
0017 00107 036000R ISZ IDATA
0018 00110 036133R ISZ COUNT
0019 00111 026101R JMP INPUT
0020 00112 026131R JMP OUT
0021 00113 000000 INONE NOP
0022 00114 103111 CLF 11B
0023 00115 103112 CLF 12B
0024 00116 102311 SFS 11B
0025 00117 026116R JMP *-1
0026 00120 102511 LIA 11B
0027 00121 012135R AND PACK
0028 00122 126113R JMP INONE,I
0029 00123 000000 INTWO NOP
0030 00124 102312 SFS 12B
0031 00125 026124R JMP *-1
0032 00126 102512 LIA 12B
0033 00127 012135R AND PACK
0034 00130 126123R JMP INTWO,I
0035 00131 000000 OUT NOP
0036 00132 126074R JMP ADCUS,I
0037 00133 000000 COUNT BSS 1
0038 00134 177742 N30 DEC -30
0039 00135 007777 PACK OCT 7777
0040          END

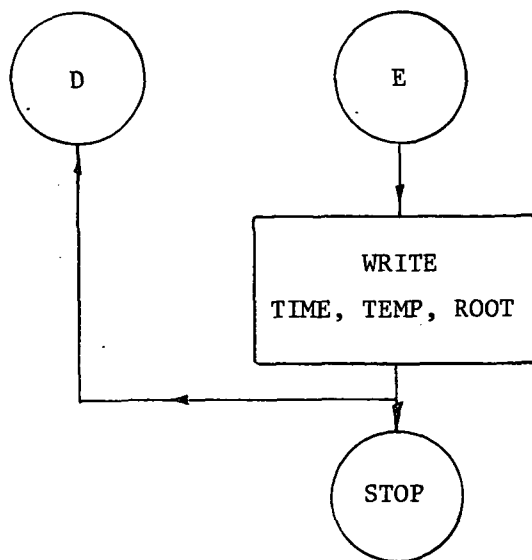
```

Figure D-1. Program BETA and ADCUS Flow Chart

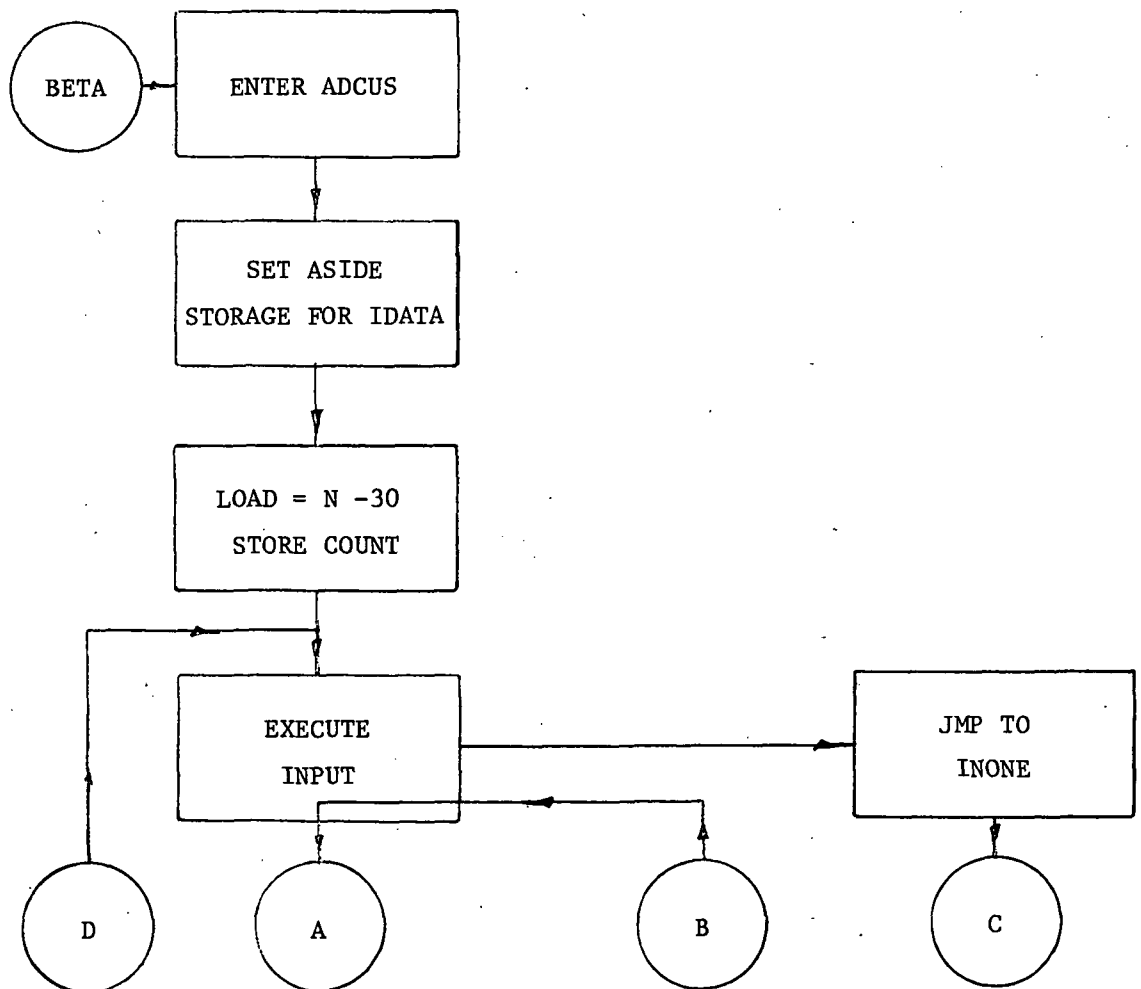


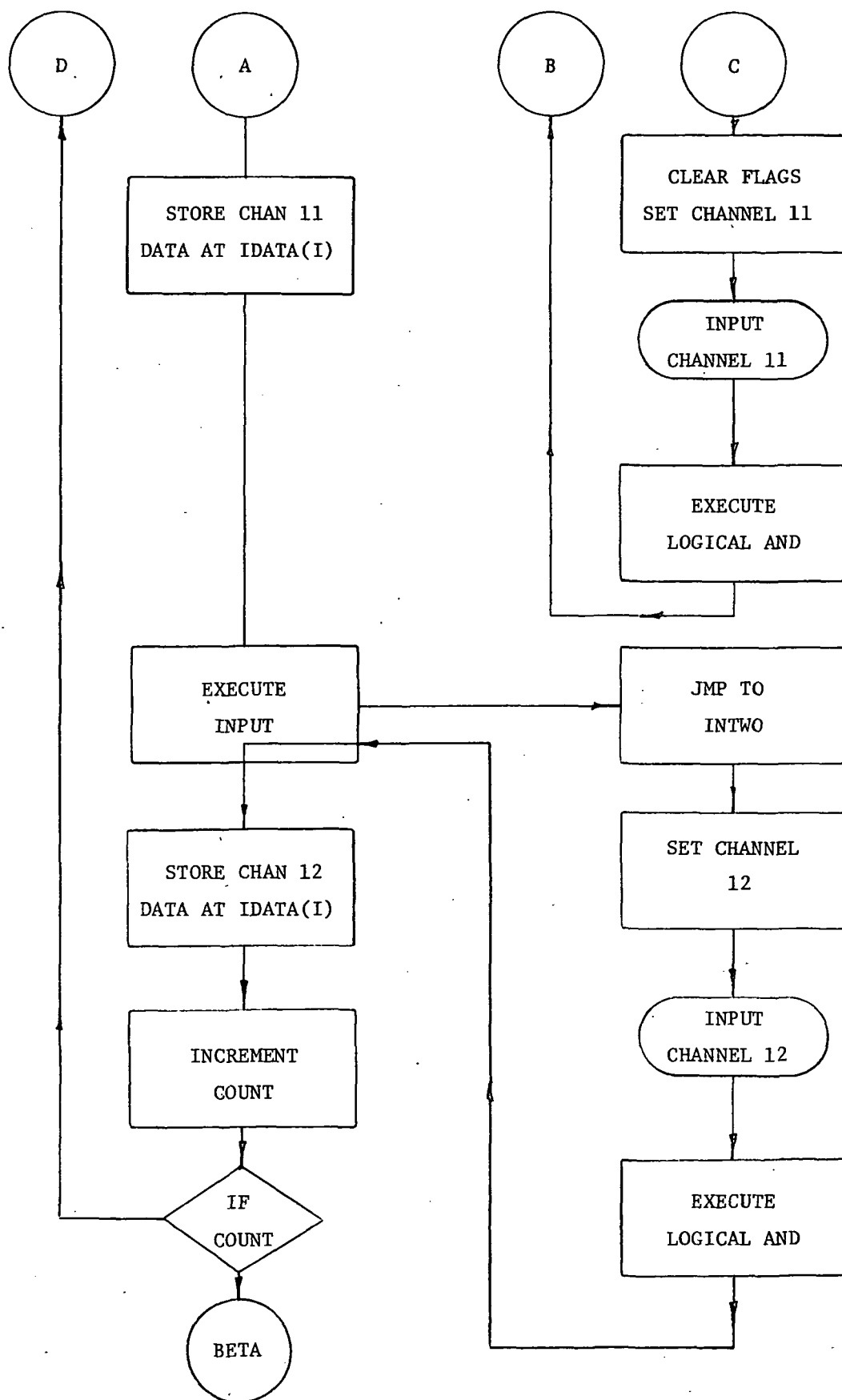






PROGRAM ADCUS





## DESCRIPTION

### PROGRAM BETA

Line 10 - 15 informs the computer that a Fortran program is to be loaded and that this program is to have a binary output tape, list output, assembly listing and a symbol table. If both the assembly listing and the symbol table are called for the first one to appear in the statement is ignored by the computer. Lines 10 - 14 through 10 - 6 are comment statements which describe the overall scope of the program. Two arrays are dimensioned in line 10 - 5. The first array is the four element constant array called CONS. This array will contain the temperature, calorimeter, and time constants. The IDATA array sets reserves storage for the transfer of 60 data words from Program ADCUS back to Program BETA.

Lines 10 - 4 through 10 - 2 are comment statements which are a guide to the operation of the program.

Lines 10 - 1 and 10 + 0 are the "WRITE" and "FORMAT" statements for printing a line on the teletype which tells the operator when to input the constants and the format for those constants. Lines 10 + 1 through 10 + 3 are comment instruction statements.

The statements which control the loading of the constants are statements 10 + 4 and 20 + 0. These are the "READ" and "FORMAT" statements for the loading of the constants.

Statements 20 + 1 through 20 + 3 are comment instruction statements.

Statement 20 + 4 is the CALL statement for calling the subroutine ADCUS. The statement has the form:



# CALL ADCUS (IDATA)

where ADCUS is the subroutine name and

IDATA is the argument of the subroutine which are transferred back to the main program.

Statements 20 + 5 through 20 + 7 initialize values for the variables N, TIME, and A1. Statement 20 + 8 sets up the increment for the time output. The increment can be either 1 second or 0.1 seconds depending on the time constant keyed in. Statement 20 + 9 calculates an intermediate variable used in the calculation of the heating rate (QUE). It is the difference of the 30th and 5th real data points multiplied by the calorimeter constants. The first constant is the value  $\frac{MC}{A}$  for the selected calorimeter. These values are contained in Table D-1. The second constant is necessary to relate chromel-alumel thermocouple output to the register capacity. That is:

4096<sub>10</sub> in the register = 10 millivolts

10 millivolts full scale = 468.5°F

Therefore, the constant is  $\frac{468.5}{4096} = 0.1143799^\circ\text{F}/\text{count}$ . Line 20 + 10 performs the final calculations of QUE. Statements 20 + 11 and 25 are the "WRITE" and "FORMAT" statements for printing QUE.

Line 25 + 1 is the "DO LOOP" control statement. This program statement sets the controls for executing statements 25 + 1 through 65, a total of 30 times in increments of one.

The infrared camera temperature data words are converted from integer to real mode through the use of the FLOAT subroutine called out in statement 25 + 2.

The real data words are then stored at TEMPR. Lines 25 + 3/and 30 are the "WRITE" and "FORMAT" for printing TEMPR.

Table D-1. Calorimeter Keyboard Inputs

Calorimeter Values for the Available Units

Calorimeter MC/A			
0.08 inch		0.25 inch	
1	.32504	1	1.11060
2	.32934	2	1.11146
5	.35523	3	1.10888
8	.33278	7	1.10802
9	.34749	8	1.10974
10	.32676	10	1.11060

For all calorimeters  $A = 0.012271875$  square ft (1.5 inch O.D.)

$C = 0.096$  BTU/#  $^{\circ}\text{F}$  (copper)

$M$  = mass from referenced report

As an example, for calorimeter #1, 0.08 inches thick,

$M = 18.85$  grams

$$\frac{MC}{A} = \left( \frac{18.85}{453.59239} \right) \cdot \left( \frac{0.096}{.012271875} \right) = 0.32504$$

\*Numbers are those referenced in Grumman Final Report, Contract No. NAS1-11537, Page 105.

As the data comes from the Adacus, 12 bits implies a full scale reading of 10 volts. In other words,  $2^{12} = 4096$  units on the register which must equal 10 volts. From the Barnes calibration table, two equations were developed to approximate the calibration curve. By examining various "fits" with this curve the relationships between temperature and output voltage was established as

$$T = 13.77 (R + 12.57)^{1/2} + 1.166$$

where  $R \leq 245.76$  register counts, and

$$T = 8.28 (R - 154.58)^{1/2} + 142.61$$

where  $R > 245.76$  register counts.

In the program line 30 + 1 is used as an IF comparison statement to establish which function to use for the calculation of temperature. Line 33 is used to calculate values of  $R \leq 245.76$  and line 33 + 1 causes the program to skip to statement 37 after this calculation. If the value of  $R > 245.76$  line 35 is used to calculate temperature.

Line 37 is used to increment TIME and line 37 + 1 is used to increment the IDATA array location to the next data point.

Statement 37 + 2 converts the calorimeter data words from integer to real and stores these data words at DQ. The "WRITE" and "FORMAT" statements for printing DQ appear in statements 37 + 3 and 40.

The calculation of  $\sqrt{\rho_{ck}}$  is accomplished in line 40 + 1. The calculation uses the formula:

$$\sqrt{\rho_{ck}} = \frac{2Q}{\sqrt{\pi}} \frac{\sqrt{t}}{T - T_i}$$

In the source language this looks like

$$ROOT = \frac{1.13 (QUE) (TIME)^{0.5}}{TEMP - CONS(1)}$$

Statement 40 + 2 is an "IF" control statement which checks the number of the computer pass. If the computer is in Pass 1 operation ( $N - 2 \leq 0$ ) headings are printed out through the use of Statements 45 & 50 followed by data print and (Statements 55 & 60). If  $N - Z > 0$  data only is printed out. Statements 45 and 50 are the WRITE and FORMAT statements for printing the headings "TIME, TEMP and ROOT." Statement 50 + 1 is a control statement which sends the computer to statement 55. Statement 55 & 60 are the WRITE and FORMAT statements for printing the data contained in the storage registers TIME, TEMP AND ROOT.

Statement 60 + 1 increments N by 1 in order to enable the computer to pick up the next data word. Statement 65 is the "CONTINUE" signaling the end of the "DO LOOP" started at line 25 + 1.

Statements 65 + 1 and 65 + 2 are "END" statements. The first end statement signifies the end of the current Fortran program. The "END\$" statement signifies the end of all Fortran programming for the compiler operation.

#### PROGRAM ADCUS

The first line of Program Adcus informs the compiler that this program is written in assembler language, the program is in relocatable form, a binary tape is produced, and that the program is listed with a symbol table. Statement 0002 defines the name of the program to be compiled and statement 0003 defines its entry point. Adcus uses a computer library subroutine .ENTR to return control to the mainline program and to insure the transfer elements of the array IDATA. The use of this subroutine is defined in statement 0004.

Line 0005 sets aside 60 words of storage for the input data. Line 0006 defines the starting point for the ADCUS execution. Line 0007 is the entry point for the subroutine .ENTR. Line 0008 defines DATA as the first storage location for the array IDATA. Lines 0009 and 0010 are the incrementers for loading the various words of IDATA. An initial constant is loaded at N30 and this value is stored at location Count. Statement 0011 is a "NOP" statement defining a location of "INPUT."

Statements 0012 through 0020 are the execution routine for the area of the program labeled as "INPUT." Line 0012 causes the program to jump to "INONE" which is a loader subroutine. This subroutine returns with one data word to line 0013 which is stored at "IDATA, I." The storage location counter is incremented at line 0014 and the program then jumps to subroutine "INTWO" at line 0015. "INTWO" essentially performs the same operations as "INONE" returning to statement 0016 with a data word. The storage location counter is incremented at line 0017 and "COUNT" is incremented at line 0018. If "COUNT"  $\neq$  0 control is transferred to line 0019 which repeats the operations of "INPUT." If "COUNT" = 0 control is transferred to statement 0020 which causes a jump to "OUT."

Statements 0021 through 0028 are the "INONE" subroutine. Statement 0021 is a "NOP" entry point for "INONE." The next two lines clear the input channels 11 and 12 of any flags that may be remaining within the computer. Statement 0024 then sets up the computer so that when the flag comes in from the a to d converter the computer will pick up the data word and jump to statement 0026. Statement 0025 holds the computer in a waiting loop between the statements 0024 and 0025 until the flag appears. Statement 0026 loads the contents of the input registers into the "A" register. The contents of the "A" register are

immediately operated on by statement 0027 which is a "logical AND." The "logical AND" statement eliminates any stray one's that might appear in bits 15 through 12 due to the mismatch of 16 bit computer words and 12 bit a to d converter words. In other words we are insuring the correctness of our data. Statement 0028 returns control indirectly to the main program.

The "INTWO" routine operates in the same way as the "INONE" routine except for the lack of "CLF" statements which are executed in the "INONE" routine and do not need to be repeated.

Lines 0035 and 0036 provide for an exit from ADCUS back to BETA once all the data has been received and initially processed.

Statements 0037 through 0039 define extra storage areas, decimal and octal constant values used in the execution of Program ADCUS.

Statement 0040 signifies the end of the Assembler language program.



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